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① LEVEL II

AFATL-TR-78-138

30 mm GAU-8 Thin-Wall Steel Cartridge Case

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DECEMBER 1978

FINAL REPORT FOR PERIOD FEBRUARY 1977-NOVEMBER 1978

Approved for public release; distribution unlimited

Air Force Armament Laboratory
AIR FORCE SYSTEMS COMMAND ★ UNITED STATES AIR FORCE ★ EGLIN AIR FORCE BASE, FLORIDA

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Development of the 30mm Thin-Wall Steel Cartridge Case was conducted, using an extrusion process with 10B22 steel. Development testing was conducted to refine the design and to modify tooling as required.

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Former case integrity problems involving transverse ruptures were resolved through use of designs of greater weight. The final case weight was about one-half pound, compared to one-third pound for the aluminum case, and over three-quarter pound for a conventional steel case.

Wall thicknesses near the base and from the extractor groove to the mouth were increased. Several interior rear wall contours were tested to determine a design with maximum resistance to transverse rupture. Three types of exterior finishes were evaluated. Testing of such designs was accelerated by use of flexible breeches on single barrel test fixtures prior to submission of designs for GAU-8 automatic gun tests. The final automatic gun tests showed a satisfactory design had been achieved.

Producibility analysis indicated substantial cost savings over the aluminum case due to lower raw material cost.

Interior volume was increased 14 percent over that of the aluminum case due to the thinner walls, affording about 150 feet per second higher muzzle velocity.

It was concluded that feasibility has been demonstrated, and it was recommended that the case proceed into full scale development and qualification testing.

PREFACE

This report provides a synopsis of the development of a thin-wall steel cartridge case in support of the GAU-8 program. The program was conducted by Amron Corporation, 525 Progress Avenue, Waukesha, Wisconsin 53186, under Contract F08635-77-C-0092 with the Air Force Armament Laboratory, Armament Development and Test Center, Eglin Air Force Base, Florida, during the period February 1977 to November 1978. The program was managed by Mr. Alvin T. Cox (DLDG).

This report has been reviewed by the Information Officer (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Gerald P. D'Arcy

GERALD P. D'ARCY, Colonel, USAF
Chief, Guns, Rockets and Explosives Division

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INTRODUCTION

This report covers the successful completion of the advanced development of a thin-wall steel cartridge case for GAU-8 ammunition. The objective was to develop a steel case with weight as near as practical to that of an aluminum case while achieving greater interior propellant volume and offering the potential for a lower cost case in mass production. Shown in Figure 1 are two successive designs of thin-wall case sections compared to the standard aluminum case section.

Previous development efforts are reported in AFATL-TR-75-139, dated October 1975, and AFATL-TR-77-53, dated April 1977. In the latter report, final tests showed no case casualties with Mader lacquer and reduced hardness levels but showed cracks and stretches with fully hardened cases. That report also covered in detail the selection of 10B22 steel material.

The initial effort under this contract was directed toward improving resistance to transverse rupture by increasing wall thicknesses by up to 0.008 inch about 1-1/2 inches from the base while holding case weight to within 0.03 to 0.04 pound above the aluminum case. The wall thickness was 0.017 to 0.018 inch at about 2 inches from the base to the case mouth.

During preliminary automatic gun tests at chamber pressures up to 60,000 psi, cases with a Mader finish appeared satisfactory while those with a DeBeers Teflon® finish failed in transverse rupture. However, during following tests of 300 Mader cartridges, rupture failures again occurred, primarily at the excess pressure levels of 70,000 psi. Work on a lot of 1500 thin-wall cased cartridges was terminated, and effort was directed toward further design variables. A lot of 86 cases, varying head to datum length, lacquer thickness, and a minor change in blend contour, still showed ruptures when fired in the automatic gun in November 1977. One of these cases at excess pressure and with the surface oiled, blew out at the unsupported area near the extractor groove. At this point, the case was redesigned, bringing the weight from near 0.37 pound to about 0.45 pound, with all wall thicknesses substantially increased. All these cases were satisfactory at both normal and excess pressure conditions. But during later tests of DeBeers coated cases at excess pressure, following frosted (-65 degree F) tests, the moisture lubrication from the preceding frosted rounds increased test severity and produced several complete ruptures. Three case designs, weighing 0.51, 0.54, and 0.57 pound, were fabricated, following flexible breech tests at the contractor's facility. During automatic gun tests in

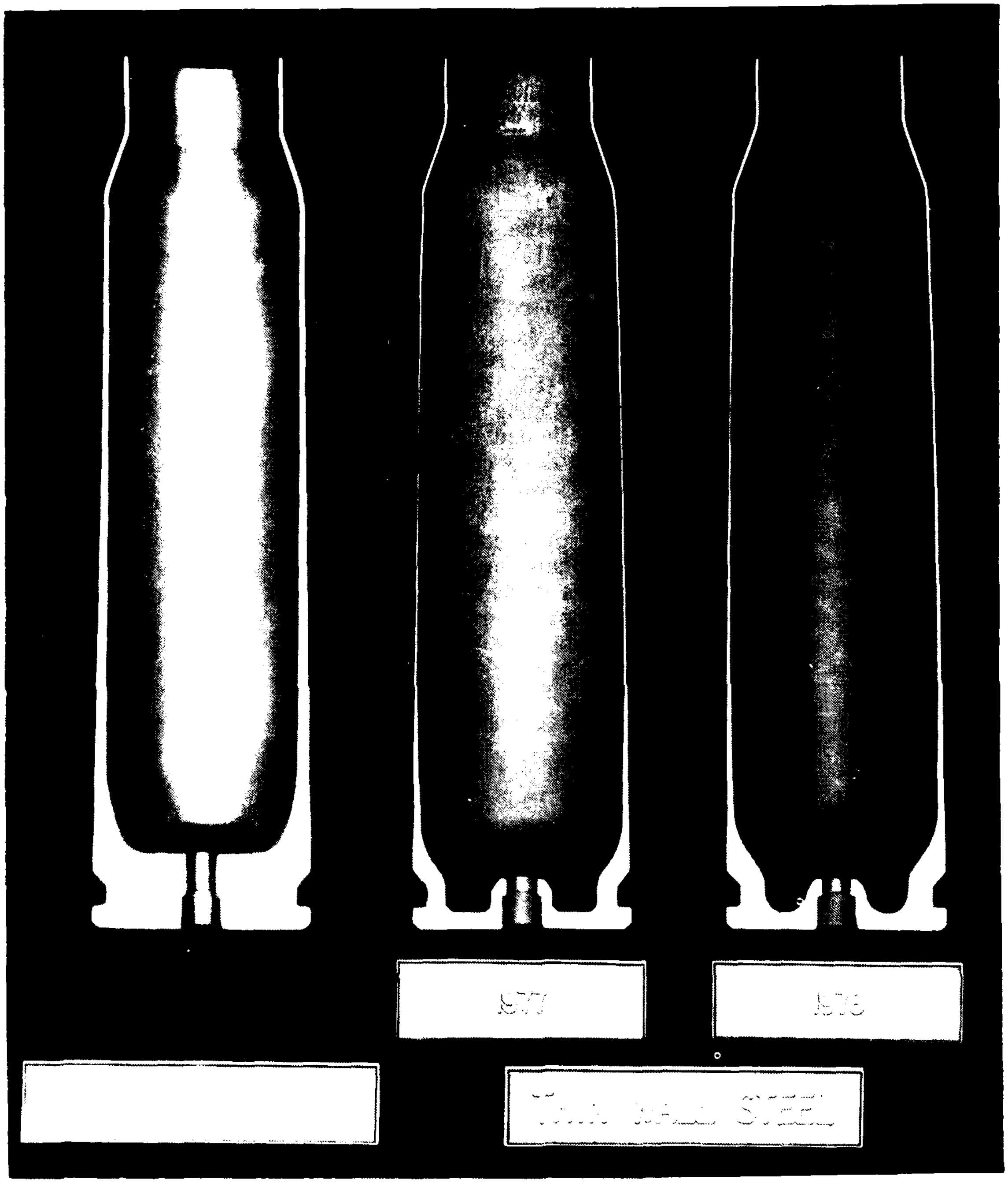


Figure 1. GAU-8 Cartridge Cases

November 1978, none of these cases showed transverse rupture. Examination for internal stretch marks showed the 0.51-pound design with Mader finish the preferred design with no stretch marks in normal type tests, and stretch marks less severe than for aluminum cases in "wet" tests, with high pressure cartridges preceded by cold frosted rounds to wet the chamber. The internal contour of the preferred 0.51-pound design appears to possess a near optimum configuration while the two heavier designs added excess metal in a zone from 1.0 inch to 5.25 inches from the base. The Mader finish was preferred, since for cases of the same design, stretch marks were more evident with the alternate DeBeers, 30 percent Teflon® type of finish.

This report covers design analysis of the various cases tested, differentiating the preferred design from the others as to design features and analysis of characteristics leading to its selection.

A producibility analysis indicated that by FY 1981 the higher cost of 7475 alloy aluminum material over 10B22 steel material appreciably exceeds the penalty in cost due to increased direct labor costs. Production equipment and processes planned for production are discussed and compared to the operational sequences followed in this contract for development quantities of cases.

Test results are summarized for tests at the contractor's facility in single barrel test fixtures and for automatic gun tests conducted by Eglin Air Force Base.

Functional characteristics are discussed as the basis for a specification to describe the GAU-8 thin-wall steel cartridge case.

SECTION II

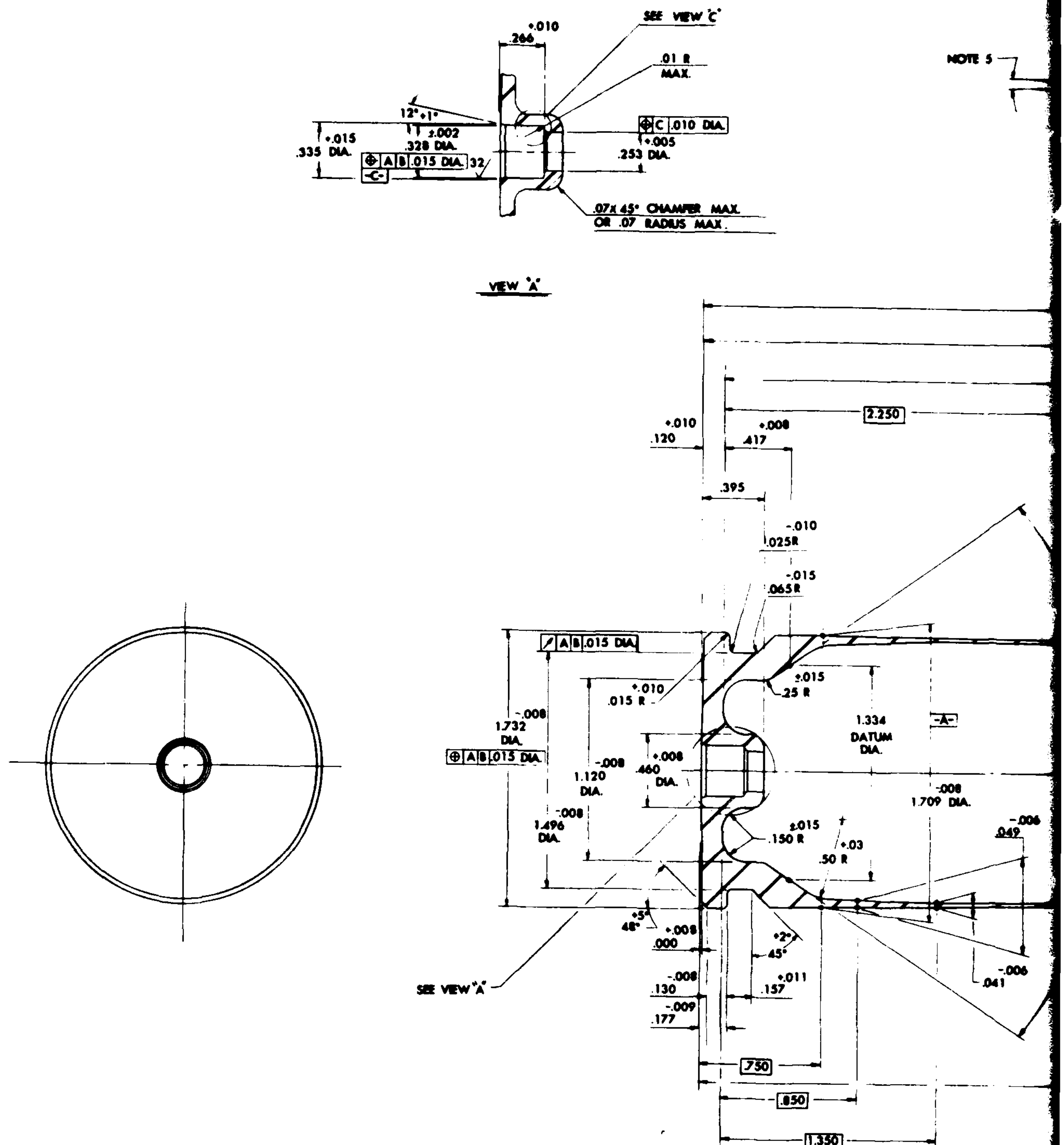
DESIGN ANALYSIS

1. INTRODUCTION

The material selection of AISI 10B22 was discussed in Section II of AFATL-TR-77-53, dated April 1977, and this material was continued in use under the present contract. The form of the steel used is cold drawn 10B22 steel, cold extruded quality B, 0.10 maximum Silicon. The diameter originally was nominally 1-11/16 inches, measuring apprximately 1.685 inches. This diameter was used in the present contract for cases up through the 0.45-pound design. For the final three designs, weighing 0.51, 0.54 and 0.57 pound, the diameter was reduced to about 1.634 inches by having the basic 1-11/16-inch rod peeled for a depth of about 0.025 inch to eliminate longitudinal seams inherent in the cold drawn rod due to build-up of scale in the rolls at the steel mill. Peeling the rod had the effect of reducing scrap rate. Prior to peeling, pieces were previously scrapped at various operations for splits obviously related to seams in the basic material. The use of peeled rod is accounted for in the material cost table of Section III, Producibility Analysis. Added costs derive from three sources: cost of material peeled away, cost of the peeling operation, and the additional freight handling costs involved. The extra cost is justified as it is more than repaid in the form of reduced scrap.

Figure 2 reflects the basic design of the Mader coated, 0.51-pound style "A" case, as reflected in Drawing Number 00012-004, selected as the preferred design after the final tests in November 1978 at Eglin Air Force Base.

Shown in Figure 3 are wall thicknesses for various case designs, magnified 100 times for ease of comparison. The lower curve for a 0.33-pound case reflects the 1975 design, approximately equal in weight to the aluminum case. The 0.37-pound design reflects cases built in 1976 and 1977, holding weight to near that of the aluminum case. Metal was added at the mouth, but partially compensated by use of a wall of constant thickness, which had the effect of reducing wall thickness about 2.0 inches from the base. The present contract initially used cases close to this design. The 0.45-pound design of 1978 increases wall thickness along the entire wall and returns to a wall thinning out toward the mouth. The increase in weight is from two sources: the increase in wall thickness as shown in Figure 3, and the increase in wall thickness under the extractor groove, clearly observable in Figure 1 by comparing the 1977 case (0.37 pound) with the 1978 case (0.45 pound). The increase in wall thickness at the extractor groove by about 30 percent



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OR .07 RADIUS MAX.
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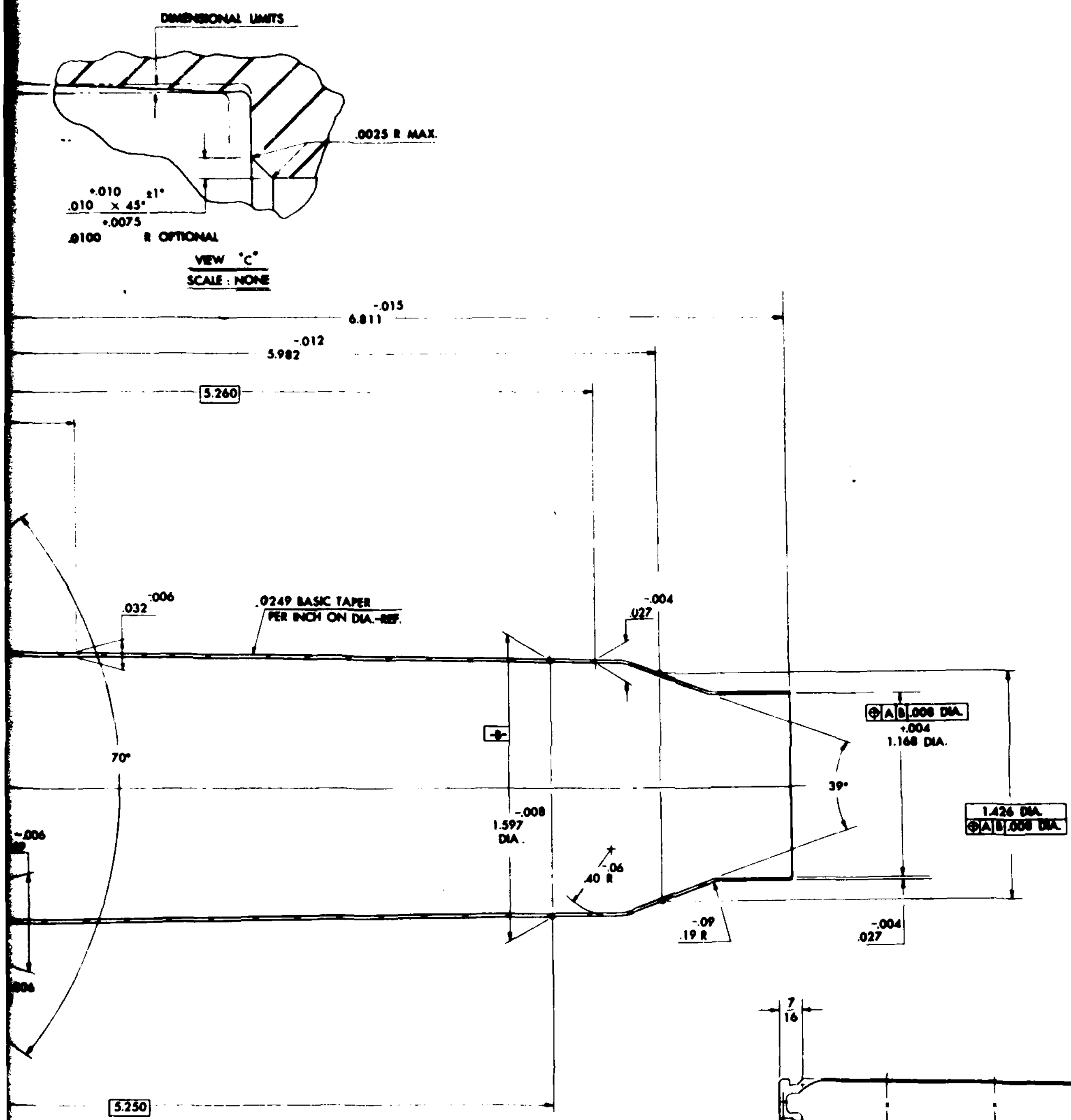

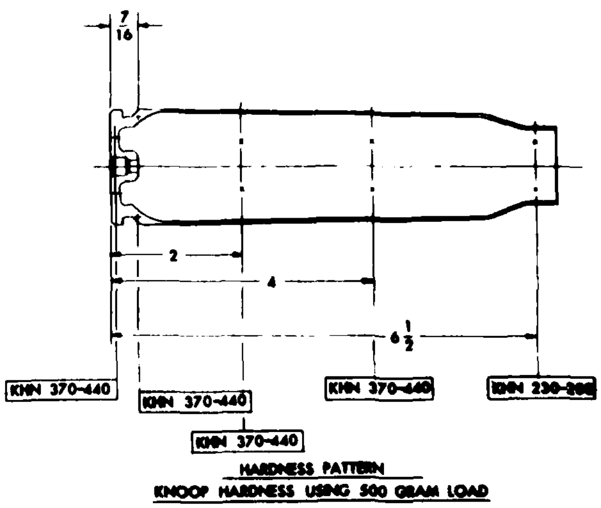

Figure 2. Style "A" Case Design

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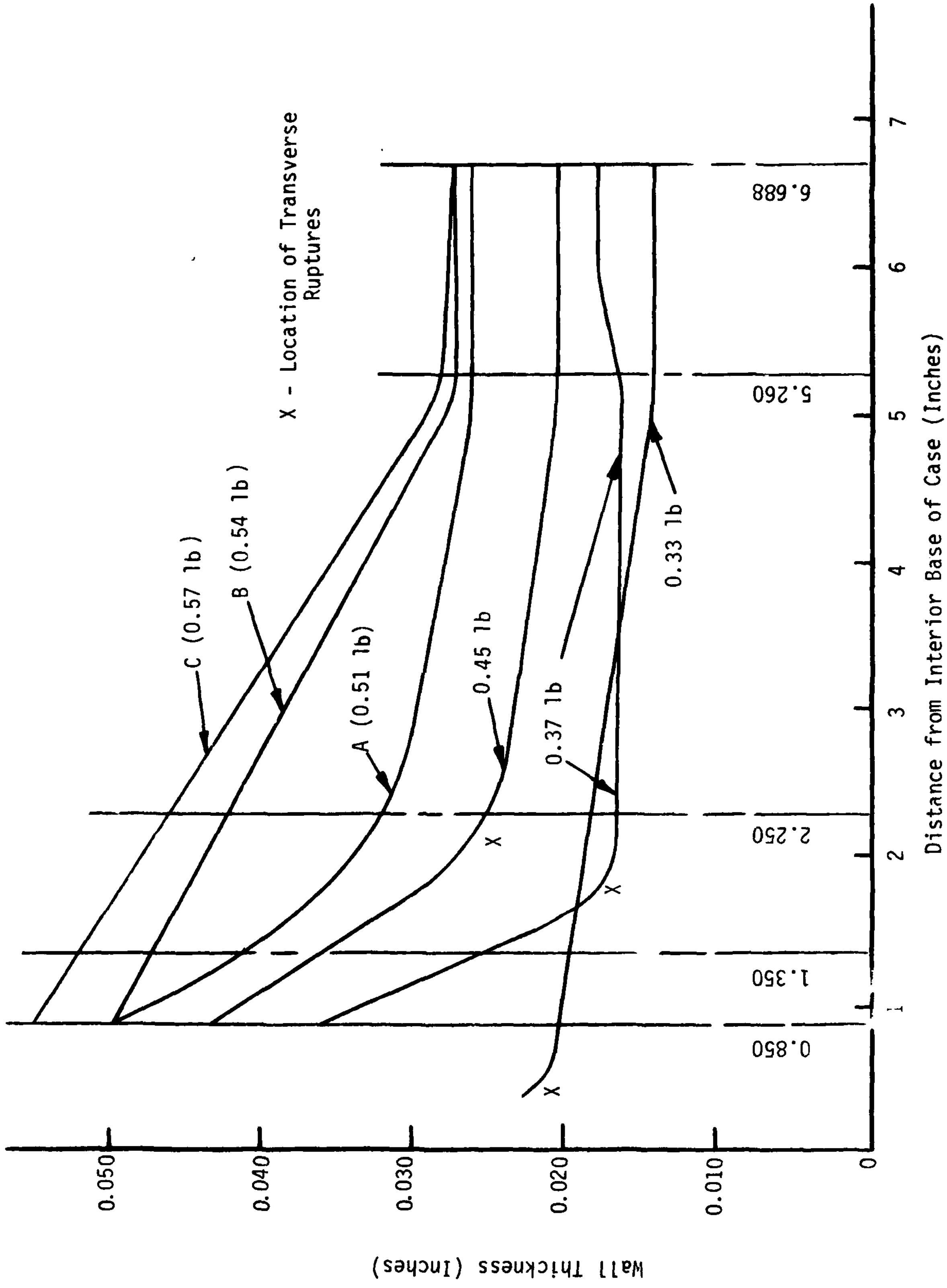


Figure 3. Wall Thicknesses

was found necessary to allow adequate strength in the unsupported area under conditions of excess pressure, excess head space, and a lubricated case. The remaining three cases, styles "A" (0.51 pound) style "B" (0.54 pound), and style "C" (0.57 pound), reflect the wall thickness of the final three designs, tested concurrently at Eglin Air Force Base in November 1978. The 0.45-pound design had experienced transverse ruptures about 2-1/4 inch from the base, with DeBeers coating, under excess pressure and "wet" chamber walls. No ruptures occurred in Designs "A", "B", or "C", but shallow interior stretch grooves were noted in all standard type tests in the automatic gun except for Design "A" with Mader lacquer. These stretch marks occurred near the 0.850 datum of Figure 3. The poorer showing of the heavier style "B" and "C" cases is attributed to a non-optimum interior wall contour, resulting in the greater stress occurring at the 0.850 datum instead of near the 2.25 datum, as noted in the 0.37-pound and 0.45-pound designs. Slope of the interior wall with respect to the outer wall between the 0.850 and 1.350 datum is about 1 degree in style "A" cases. For styles "B" and "C", this is too shallow, near 0.3 degrees. Prior designs, such as the 0.37-pound design, were too steep (2.2 to 3.4 degrees).

All four draw punches were successively ground to produce the successively heavier case styles; therefore, the final punches produced the 0.57-pound design. A revision to Figure 2, style "A" drawing number 00012-004, reflects actual wall thicknesses as measured for style "A" cases, which were near the upper limit of wall thicknesses called for, and to apply a slight increase in mean wall thickness at the 0.850 datum. The latter change increases the weight only from 0.507 pound to 0.508 pound and decreases the interior volume from 11.78 cubic inches to 11.77 cubic inches. Maximum change to the drawing is at the 0.850 datum with an increase in wall thickness of 0.006 inch. Minimum change is at the mouth with an increase of mean wall thickness by 0.002 to 0.027 inch to reflect actual mean wall thickness of style "A" cases tested.

The hardness levels are shown as values for Knoop hardness using a 500-gram load, as the preferred procedure for hardness measurement of thin-wall steel cases. The base and body hardness values of KHN 370 to 440 reflect the necessary balance between excess head growth in the unsupported area or hard extraction if too soft and lack of ductility if too hard. The mouth hardness range specified of KHN 230 to 280 reflects the elimination of a separate mouth anneal operation to achieve the desired bullet pull, and the results of body anneal followed by tapering of the forward end of the case.

2. STRESS LEVELS AND EXTRACTION FORCES

Metallurgical charts relate hardness levels to ultimate tensile strength, and the stress levels associated with the thin-wall material were originally estimated from hardness values. However, in 1977 several coupons were cut from various cases with hardness ranging from R30N 53 to 59 hardness, and subjected to tensile tests in Tinius Olsen machines. Results are plotted as the lower curve in Figure 4. Three hardness scales are shown: Knoop, Rockwell C, and Rockwell 30N. Reliable hardness levels for thin material are best obtained by the Knoop method. This is then converted to the Rockwell scales. The upper curve of Figure 4 reflects the commonly published conversion chart data for steel material. The thicker, lower hardness material from 10B22 steel, as used in Oerlikon 831L 30mm conventional steel cases, falls directly on this curve at 120,000 psi ultimate strength for hardness R30N 46. That case material is the same as used for the GAU-8 thin-wall case. Results of high and low strain rate tests by the Materials Laboratory at Wright-Patterson Air Force Base bracket the conventional curve, with high strain rate values above the curve and low strain rate values below the curve. The lower values for the thin-wall case are associated with the thinner material. Data points are shown for cases with walls about 0.017-inch thick. The value of 145,000 psi for a hardness of R30N 59, at the middle of the specified hardness range, is the average of about a dozen coupons, ranging from 130,000 psi to 160,000 psi strength. A more recent test of coupons at this hardness level from walls of case type "A" (0.51 pound) averaging 0.027-inch thick, showed an average ultimate tensile strength of 160,000 psi. Applying the value of 145,000 psi ultimate strength to the stress-strain plot of Figure 5 for a case of maximum clearance in the chamber, the case contacts the chamber wall at a strain of 0.008 inch/inch. For a final pressure of 66,000 psi in the chamber, the chamber expands by 0.009 inch corresponding to a strain of 0.0052. As stress in the chamber drops to near zero with pressure drop, the slope of the stress-strain curve for both chamber and case follow the steel modulus line of 30,000,000 psi, and the case ends up with an interference in the chamber of 0.0007 inch.

By use of Lame formulae for a steel shell under compressive external pressure, the pressure necessary to create this interference in a steel case 0.016-inch thick is 221 psi compressive loading, or 419 psi for the later type "A" case with walls 0.030-inch thick near the transition blend zone. For these pressures, extraction forces can be calculated from the case surface area and an assumed coefficient of friction, yielding an extraction force of about 1100 pounds for the thinner wall, and a value of friction coefficient of 0.18 for Mader lacquer, corresponding to measured extraction forces of the order of 800 pounds for the thinner walled cases.

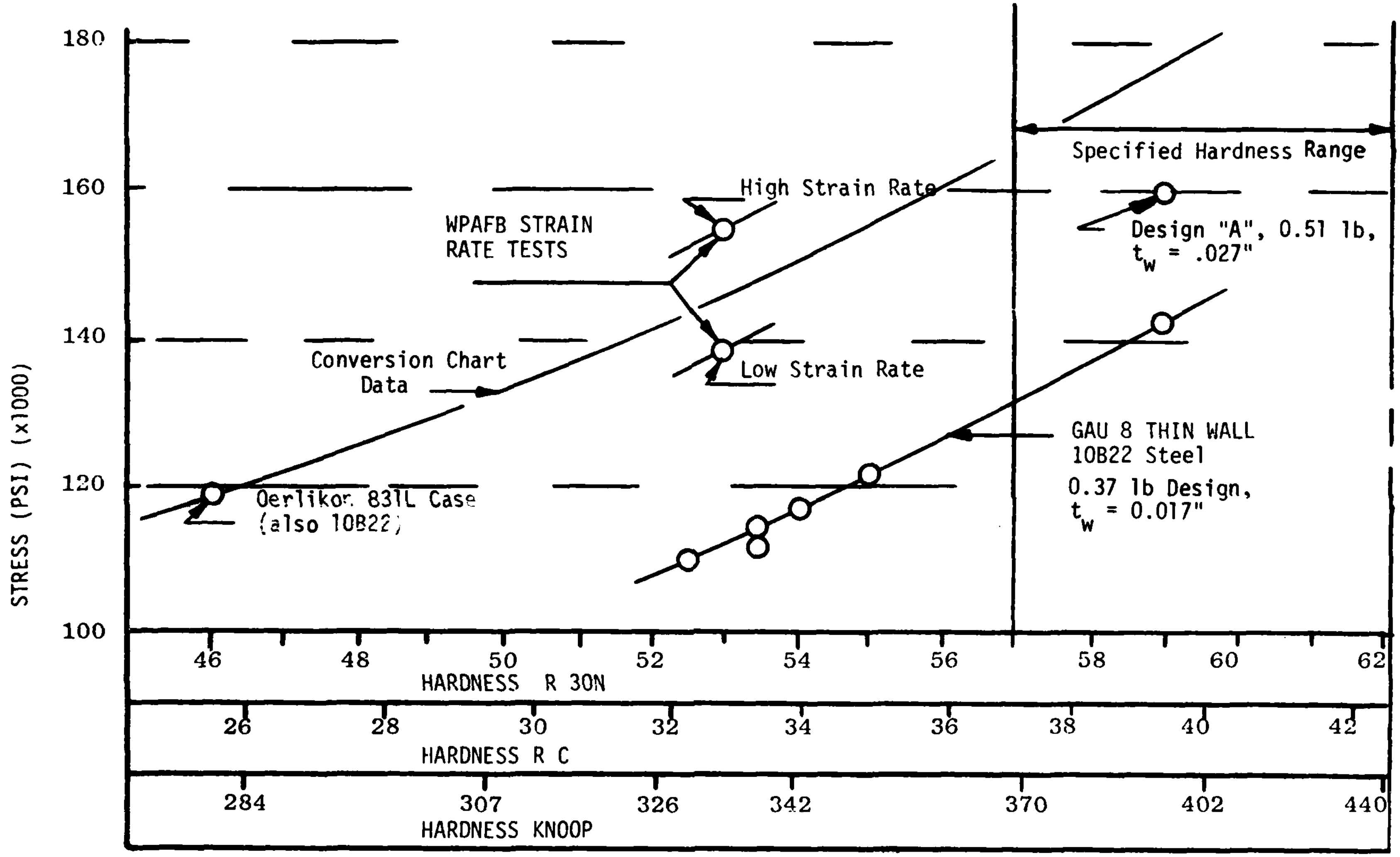


Figure 4. Case Ultimate Strength Versus Hardness

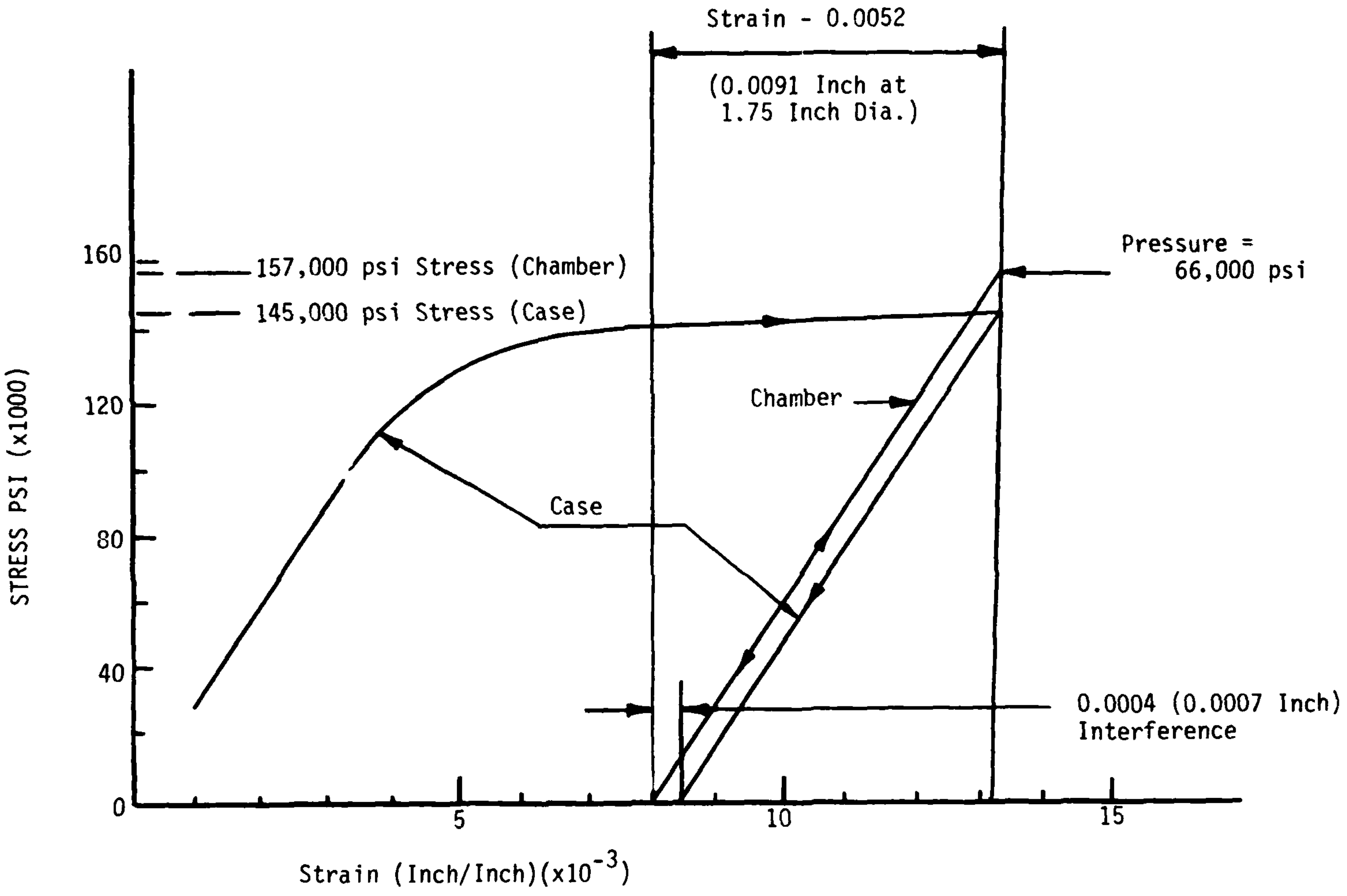


Figure 5. Case - Chamber Interference

Shown in Figure 6 is a plot of extraction force versus peak chamber pressure for a standard aluminum case and two thin-wall cases of the 0.45-pound design, with wall thicknesses of about 0.023 inch, one with Mader lacquer coating (higher friction) and one with a DeBeers Teflon® coating (lower friction). The aluminum case is found to be intermediate between the two steel cases, with the Mader coated case above the aluminum case and the DeBeers coated case below it.

Strength of material formulae used to calculate data for the preceding figures are summarized as follows:

For Figure 5, case-chamber interference:

$$\Delta A = P \frac{A}{E} \left[\frac{B^2 + A^2}{B^2 - A^2} - \nu \left(\frac{A^2}{B^2 - A^2} - 1 \right) \right]$$

Chamber strain = $\Delta A/A$

Chamber stress = Chamber strain times modulus of elasticity, E

where:

A = Chamber inner radius, inch

ΔA = Change in chamber radius due to internal pressure

P = Internal chamber pressure, psi

B = Chamber outer radius (one-half barrel diameter)

ν = Poisson's ratio, 0.26 for steel

E = Modulus of elasticity for steel, 30,000,000 psi

For Figure 6, case extraction forces:

$$\sigma_T = -p \frac{(1 + A^2/B^2)}{(1 - A^2/B^2)}$$

$$\sigma_T = \frac{uE}{B}$$

$$F = pA_s f$$

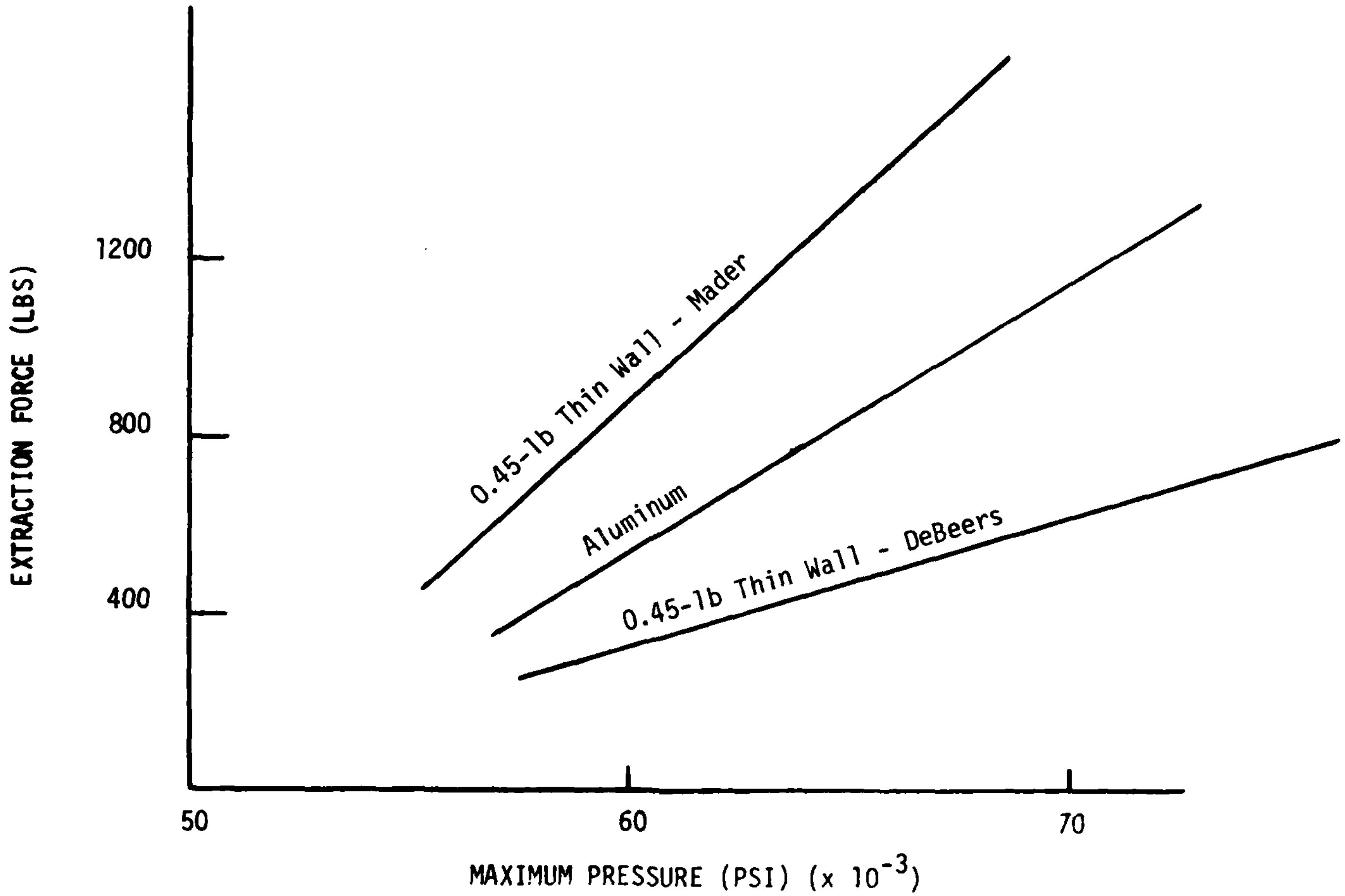


Figure 6. Case Extraction Forces

where: A = Case, inner radius, inch

B = Case, outer radius, inch

p = External pressure on case wall exerted by chamber due to interference fit, psi

σ_T = Tangential compressive stress in case wall, psi

u = Radial interference fit (half of diametral interference, calculated graphically from Figure 5)

E = Modulus of elasticity for steel, 30,000,000 psi

F = Force to extract case, pounds force

A_s = Surface area of case, square inches

f = Coefficient of friction at case wall

3. COMPUTER STRESS ANALYSIS

A finite element stress analysis of the GAU-8 Thin-Wall Steel Case was conducted by the Army for the Air Force. Shown in Table 1 is an extract from this study relating to shear stresses in the unsupported area of the case head under the extractor groove. The two thin-wall cases shown in Figure 1 are identified as "1977" for the original base section and as "1978" for the reinforced base section. Table 1 indicates the 1977 case is marginal in strength, while the 1978 case has an adequate safety factor. In this area, the computer stress analysis provided useful design data.

The problem of identifying areas of the case wall to be reinforced to prevent transverse rupture is more difficult to analyze. Due to limits of the computer finite element program, the computer could not take into account the effects of sliding friction forces as the case is stretched on pressure rise, could not allow for the dynamics of such stretching action, and could not present strain values which determine the imminence of rupture. As pressure rises, in a case with normal clearance, the stress in the case wall exceeds the ultimate value, and failure is prevented by the support offered by the chamber. Transverse rupture can occur when longitudinal case strain due to flexure in the gun locking mechanism becomes excessive.

TABLE 1. COMPUTER SHEAR STRENGTH

Given Strength of 10B22 Boron Steel of Case:

Tensile, Ultimate: 145,000 psi

Tensile, Yield: 110,000 psi

Assuming Shear Values Half These Values
(Mohr's Circle, $\tau = 1/2\ \sigma$)

Shear, Ultimate: 73,000 psi

Shear, Yield: 55,000 psi

Computer Values of Shear Stress at Unsupported Head Region:

Maximum Chamber Pressure	1977 Case	1978 Case
68,000 psi	52,200 psi	27,700 psi
80,000 psi	57,900 psi	33,900 psi

These values support test results, namely:

1977 case failed at 76,000 psi in worn gun, 0.040 excess head sapce.

1978 case tested excess pressure in Mann barrel, no failure with excess head space up to 0.120.

Figure 7 roughly depicts observed friction effects at the case wall and possible effects on transverse rupture. From friction coefficient work on case finishes by Midwest Research, it was determined that the change in friction coefficient from static to dynamic was strongly positive for Mader lacquer, compared to the usual negative value for dry metals such as zinc plate on steel. Mader lacquer experimentally offered the greatest resistance to transverse ruptures of various finishes used. In flexible breech tests, with copper washers deforming behind the head of the case in firing, it was observed that only the Mader coated cases showed no growth on firing. Cases with other finishes showed growth in length of the order of 0.030 inch. The lower part of Figure 7 speculates on the possible stretch mechanism. As pressure rises with time, circumferential case elements alternately slip, then seize to the wall, and slip again in a see-saw fashion, and if friction forces, at the moment of breakaway, suddenly drop, the ensuing amplitude of vibration is more violent than if the friction force builds up at breakaway. The latter action can, in effect, act to dampen out the oscillations and reduce peak strains.

Shown in Figure 8 are various sketches and graphs to identify the technical mechanics of the stresses involved.

The rear half of a case is shown schematically with the rotor connecting barrel to bolt given a flexibility by the spring constant, k. For a pressure of 71,000 psi, the pressure force to the rear is the order of 152,000 pounds force (compared to 124,000 pounds force for the aluminum case, which has thicker walls). Calibration of copper washers in a Tinius Olsen machine reveals that 75,000 pounds force goes to the face of the bolt, with the remaining friction force, F_f, of 77,000 pounds dissipated along the walls of the case. The free body is of the case element isolated by sections 1 and 2. Ideally, stress is the same all along the wall, with $\sigma_1 = \sigma_2 = \sigma_x$ for equal likelihood of excess stretches occurring anywhere along the case. Due to the friction force, F_f , the wall must taper, with t_2 less than t_1, for σ_1 equal σ_2. The problem is to determine the inner wall contour which meets this criterion. The friction coefficient versus velocity plot is merely to indicate that some relationship of this type exists for various finishes. Treating each successive ring-shaped free body as both a spring and a mass, with damping present, the differential equation for a dynamic analog becomes:

$$m\ddot{x} + m\dot{x} + kx = F(t)$$

FINISH	Δf_{S-D}
DRY METAL	−
MADER LACQUER	+

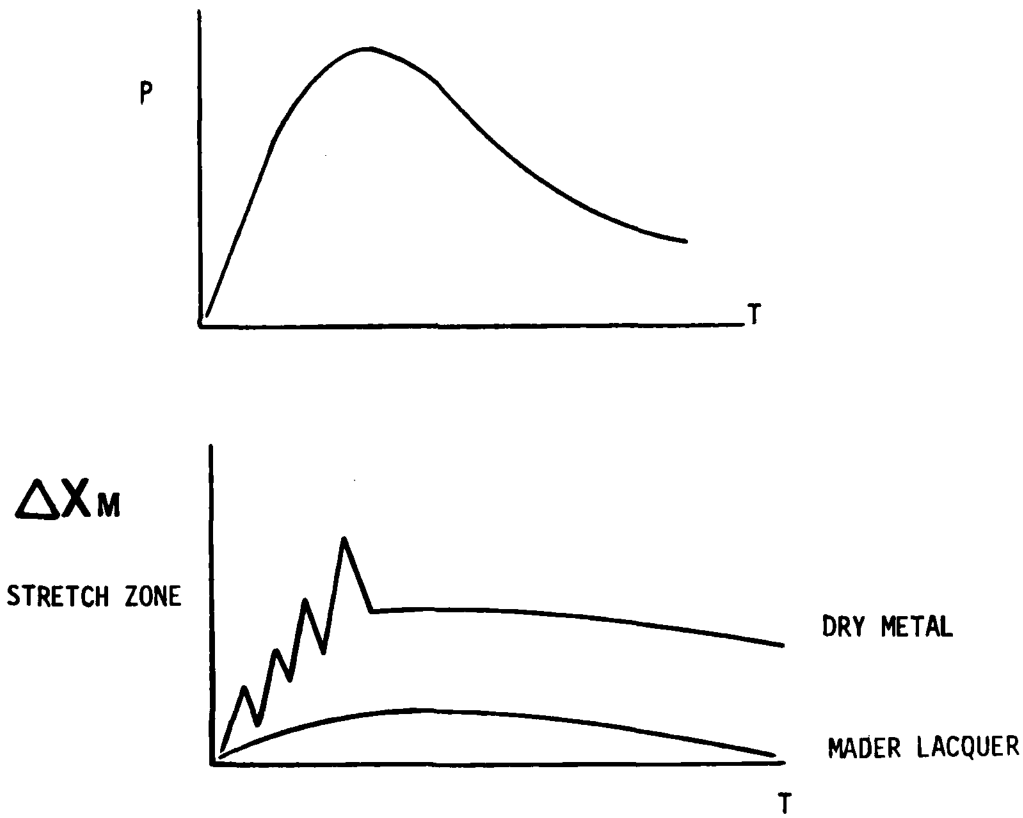
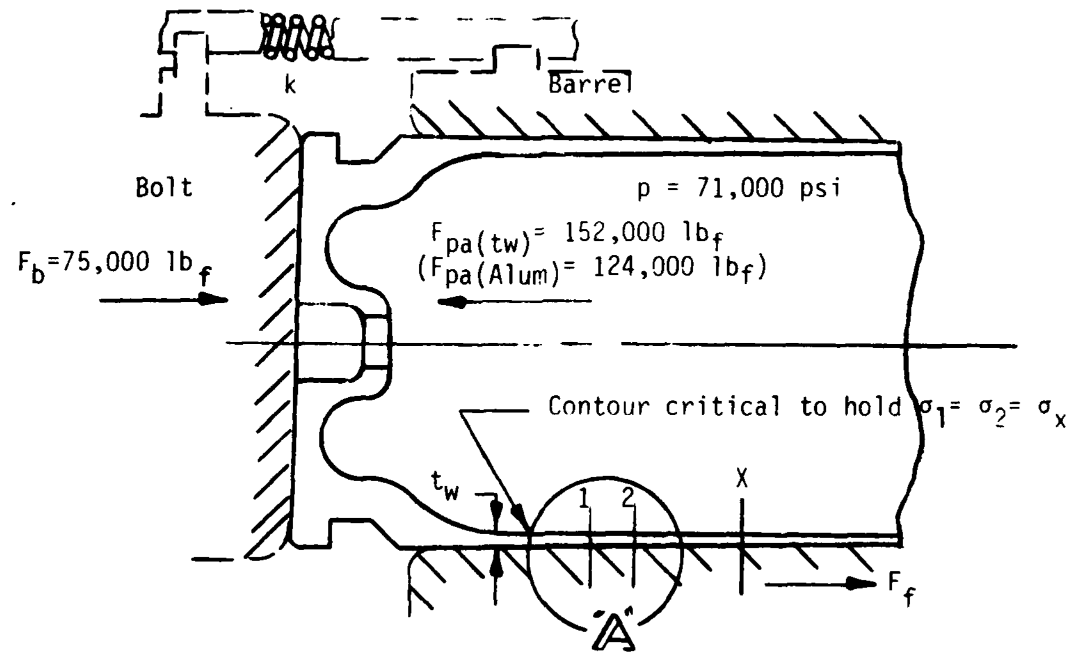
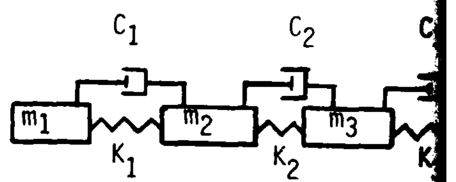


Figure 7. Friction Effects



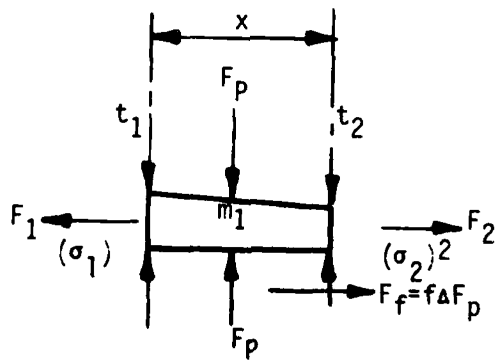


Dynamic Analog

$$m\ddot{x} + c\dot{x} + kx = F(t)$$

Differential Equation

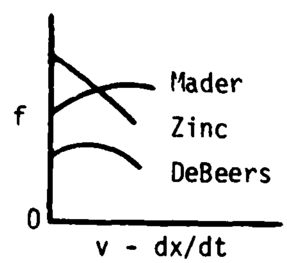
$F_1 = t_1 c\ \sigma_1$



Free Body at "A"

$$F_1 = F_2 + \Delta F_f$$

$$\therefore\ t_2 < t_1 \text{ for } \sigma_1 = \sigma_2$$



Friction Coefficient versus Velocity

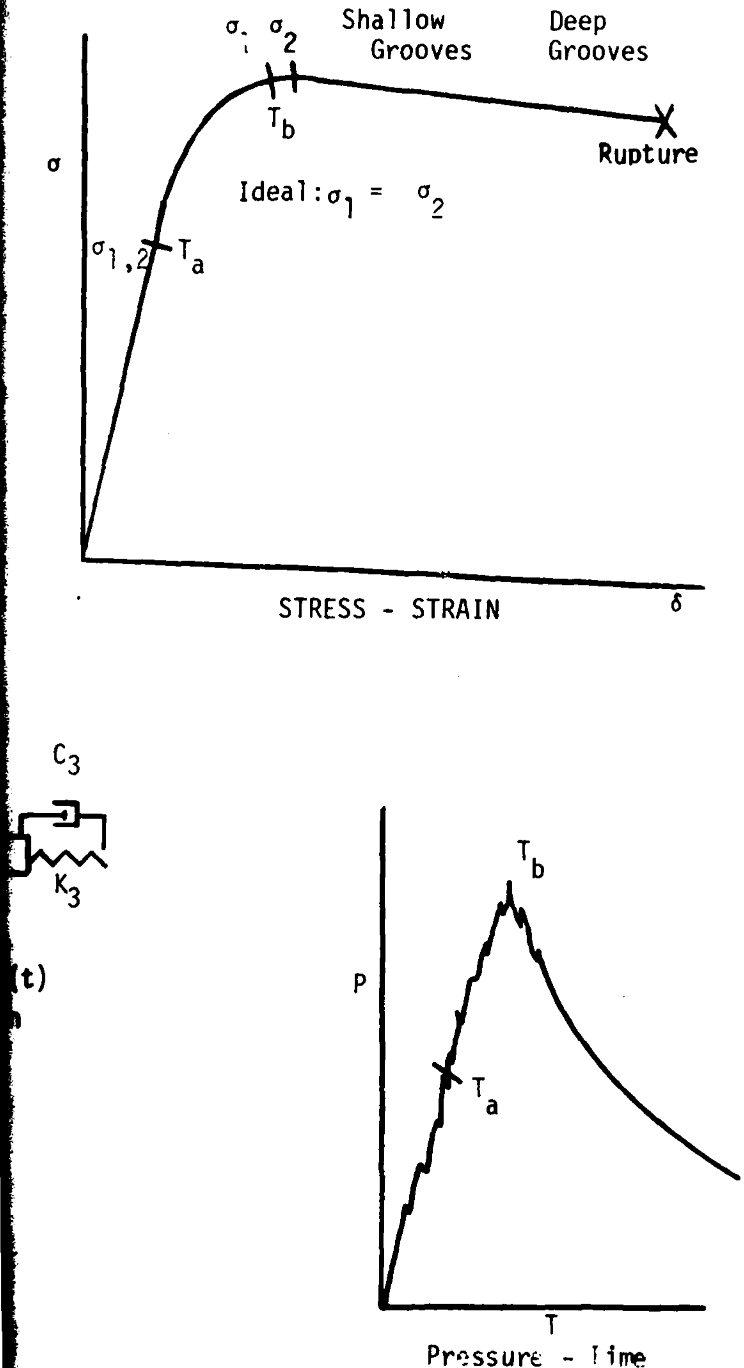


Figure 8. Stress Analysis Elements

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The input forcing function, F (t), is the force exerted by the head of the case on the case walls, induced by the gas pressure forces depicted in the P-T diagram, with some "hash" evident, as noted in oscilloscope traces. The stress-strain curve at upper right shows that, ideally, σ_1 and σ_2 are equal and coincide for a given instant of time. From the stress-strain curve of 10B22 steel at 145,000 psi ultimate strength, excess strain first manifests itself in the form of shallow grooves in the case, next deep stretch grooves, and finally rupture. Excess diverging oscillations of longitudinal strains due to lack of damping action at the finish can lead to rupture, and a condition of excess strain on one side of the case, caused by thinner walls on one side or lower hardness on one side, can increase the likelihood of rupture.

The foregoing is presented as an oversimplified statement of the problem. Computer and mathematical techniques will be used for future development of design techniques other than use of the traditional "cut-and try" method used to develop the inner contour of this thin wall steel cartridge case. The "cut-and-try" method of case design over the past three years has led to the conclusion that the initial inner wall slope with respect to the outer wall, between the critical 0.850 and 1.350 datums, should be about one degree, with 2.2 degrees too steep, and 0.3 degree too shallow. It is of interest to work backwards and determine from a free body case element in this zone the implied effective friction coefficient, making the assumption that stress levels are equal and are in the yield region of about 145,000 psi at a pressure assumed to be 65,000 psi. The following equation is derived from a free body diagram such as sketched in Figure 8:

$$F_1 = F_2 + pA_B f \qquad \text{Where: } \sigma_1 = \sigma_2 = 145{,}000 \text{ psi}$$

or $$\sigma_1 A_1 = \sigma_2 A_2 + pA_3 f \qquad p = 65{,}000 \text{ psi}$$

To find A_1 or A_2:

$$A = \frac{\pi}{4} \left(d_o^{\,2} - d_1^{\,2}\right)$$

Where d_o = outer diameter

d_i = inner diameter of the case at sections 1 or 2

A_3 = case surface area between sections 1 and 2

f = mean effective friction coefficient at case surface

Using typical values for case design type "A", the implied effective friction coefficient is found to be 0.04, appreciably lower than for laboratory-measured values of f for any case surface finishes. One interpretation of this anomaly is to consider that at high velocities, and at high frequency oscillations, the mean friction coefficient does drop, and that for a finish such as Mader lacquer, the lacquer properties allow a better damping force action. Handbooks indicate an appreciable drop in friction coefficients with increase in velocity.

4. PRESSURE REQUIRED FOR CHAMBER CONTACT

An analysis of the chamber pressure required to produce contact with the chamber wall was prompted by the observance that the earlier style thin-wall cases had more nearly uniform wall thicknesses over much more of the case than for conventional cases, and the speculation that the case walls should contact the chamber as pressure rises in such a way as to "squeeze out" any trapped air that might serve temporarily as a lubricant, thus encouraging transverse rupture. In most conventional cases, the thinner forward wall induces first contact near the mouth and, successively, contact toward the rear of the case. In making this analysis, it became apparent that not only wall thickness influences first case contact but also the amount of clearance between the case and the chamber. As pressure rises, and stress-strain is still in the elastic regime, it takes appreciably more pressure to move the case out to the chamber with maximum clearance than for minimum clearance. Figure 9 shows the results of a study of actual case clearance, with clearances amplified 200 times for easy visibility. The upper plot shows case diameter variations from mean diameters at the specified taper of 0.0249. This same data is translated below to values for diametral case to chamber clearances. It is noted that a case has minimum clearances at two points, one near the base and one about 4 inches from the base. In between, diametral clearances may range up to 0.008 inch greater than at the tightest points. Once clearance is determined, the strain required to produce chamber contact is calculated as a function of distance from the base. Stress is then evaluated from stress-strain curves, as shown in Figure 10. Note that the body has higher stress values than the mouth and neck area, as the main body of the case is harder. Finally, pressure within the case required to produce that value of stress is calculated from the equation:

$$P = \frac{2 \sigma t_w}{D}$$

Where P = pressure, psi

σ = stress, psi

t_w = wall thickness, inches

D = case diameter, inches

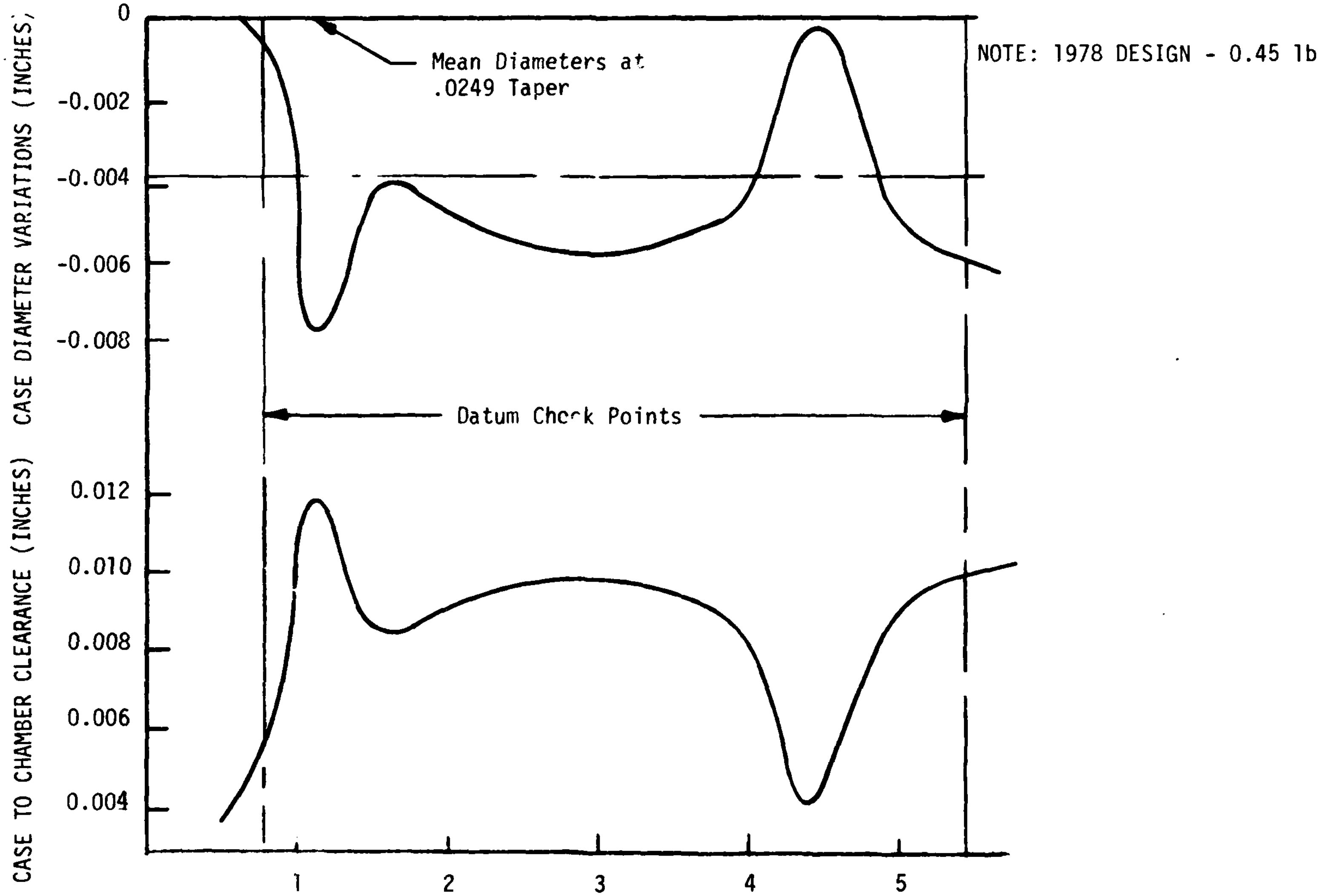


Figure 9. Case Clearances

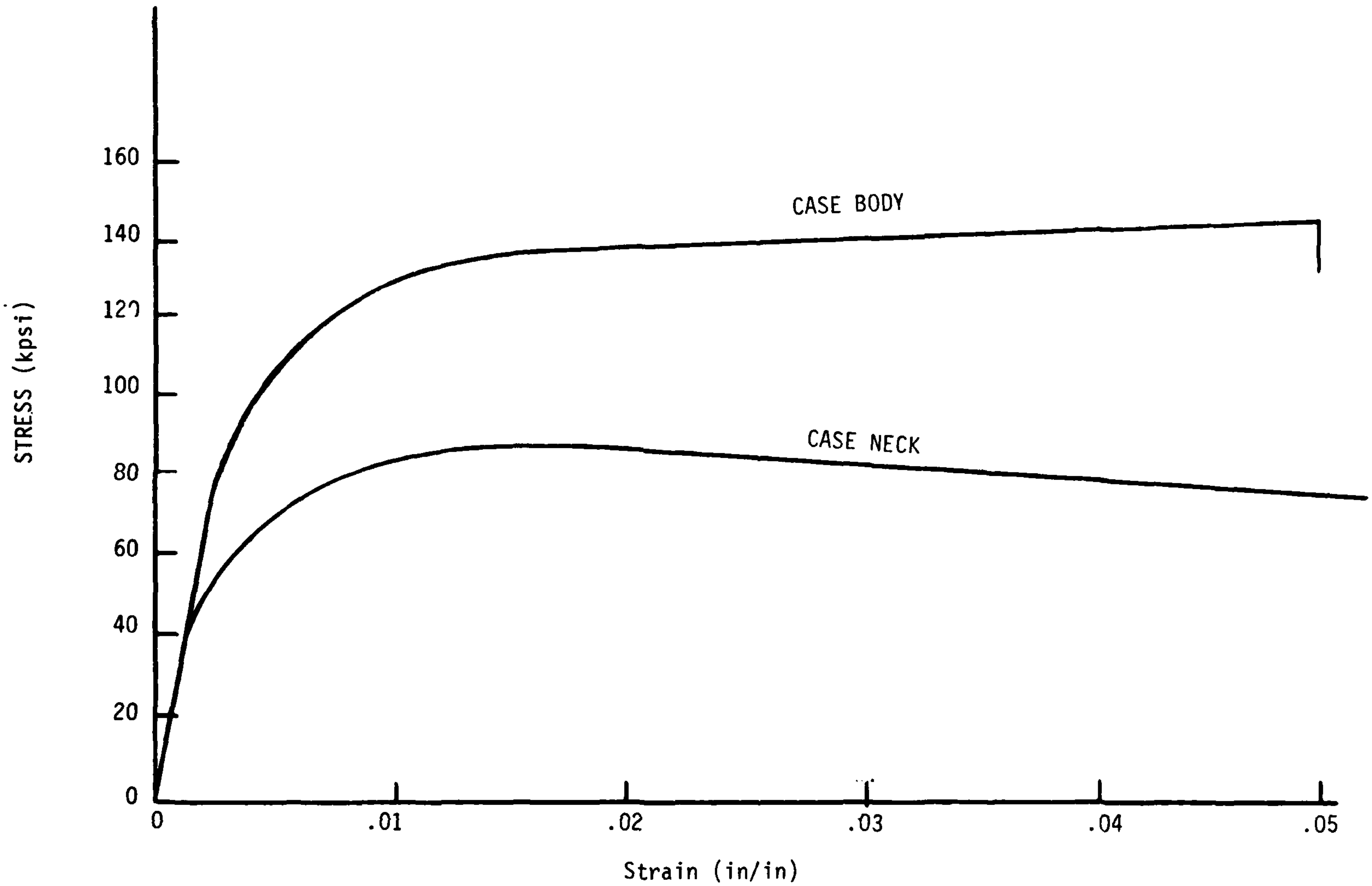


Figure 10. Stress-Strain Curves

Results are plotted in Figure 11 for various case designs. The data indicates that the 0.45 pound design contacts at 3 inches and 6 inches first, trapping a small pocket of air in between. Whether this has any adverse effect on incidence of transverse rupture is doubtful; stress levels due to case wall contour probably play a much more prominent role. However, it is noted that subsequent heavier case designs and the standard aluminum case are not configured to cause erratic wall contact, but rather a smooth transition occurs, with first contact near the case mouth.

5. BULGE DUCTILITY

Attached as Appendix A to this report is a report by Dr. Volker Weiss and Mr. John Biegel of Syracuse University on "Hydraulic Bulge Ductility of Amron Thin-Wall 30 mm Steel Cartridge Cases."

The bulge ductility technique developed at Syracuse University subjects the thin wall of a pressure vessel or membrane to hydraulic pressure until rupture occurs and analyzes the resulting strain after measurement of the membrane thickness before and after rupture. Such apparatus could be useful in determining the ductility of new case wall material, varying parameters such as wall thickness and hardness. Maximum ductility to resist transverse rupture would be the objective within limits of other constraints.

The assumption made in Appendix A that σ_3 = 45 ksi is on the low side, since all case restraints were not given to Syracuse University. Actually, due to case-to-chamber clearance, and expansion of the chamber, σ_3 is close in value to σ_1, taken in this report as 160,000 psi. With this change, α remains the same, but β is changed to a value about 1.0 instead of .28. Applying the appropriate values to Figure 1 of Weiss STP 605, 1976, "Microstructure Aspects of Fracture Toughness," a ductility index near 1, instead of 2.8 is obtained, predicting that the hydraulic elliptical fixture results are directly comparable to actual case firing results.

Measuring an Eglin-fired ruptured case as to original wall thickness, t_o (a short distance from the rupture), and final wall thickness t_f (at the rupture), a comparison can be made between a linear-pulled laboratory coupon test, an Eglin-fired case, and the hydraulic fixture.

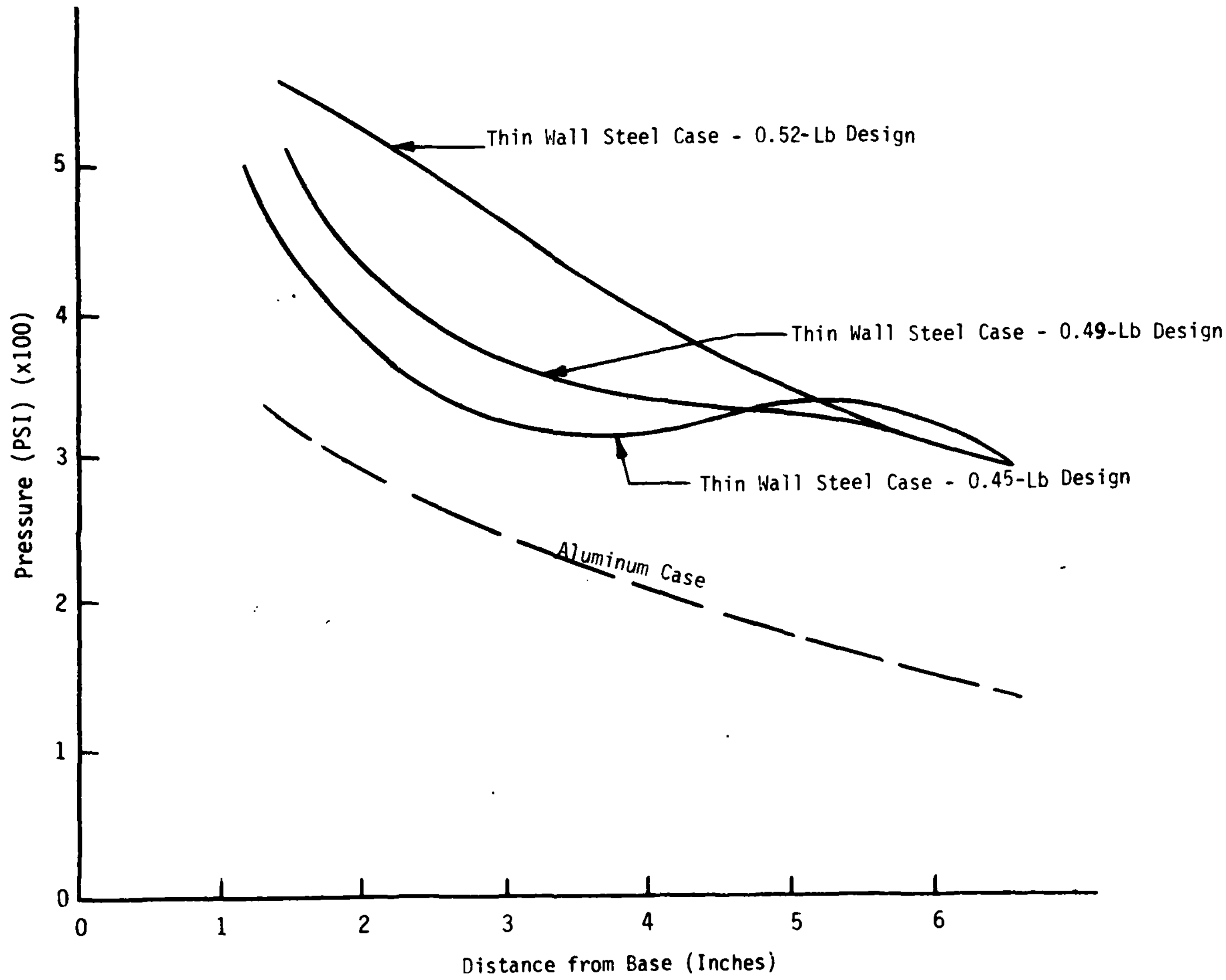


Figure 11. Chamber Pressure at Initial Complete Contact, Various Designs

Results were found as follows:

Value (Inches)	Coupon Test	Eglin-Fired Case	Hydraulic Fixture
t_o	0.017	0.0185	0.0190
t_f	0.014	0.0125	0.0138
$t_o - t_f$	0.003	0.0060	0.0052
Fracture strain ($\ln t_o/t_f$)	0.19	0.39	0.32

The conclusion is drawn that the hydraulic elliptical test fixture will predict fracture strain more accurately than a simple tensile coupon test.

6. NATO RELATED ASPECTS

Introduction

Applicability of the thin-wall case to other NATO guns has been briefly evaluated where interchangeable ammunition is theoretically possible, with resolution of the problem of the percussion primer (GAU-8 ammunition) and electric primer (European ammunition). Assuming that the smaller numbers of NATO weapons implies resolution of the primer problem in favor of a change in the European guns to permit use of the percussion primer, other potential problem areas are addressed.

High Set-Back Forces in Mauser Gun

Tests of aluminum-cased cartridges in Mauser 30 mm guns have indicated the high set-back on ramming the cartridge can move the WECOM 30 flash tube, retained only by the M36 primer, back into the primer with sufficient force to activate the primer. Various potential primer systems are shown in Figure 12. In the upper sketch, the flash tube is made an interference fit with the case. In the event compressed air under the primer at assembly becomes a problem, a relief vent could be provided. Existing flash tubes would be enlarged for about 1/4 inch from the base, or the case flash hole could be reduced in diameter. The second sketch shows a lock washer retaining the flash tube from rearward movement. However, force levels are much lower with the lock washer than with an interference fit.

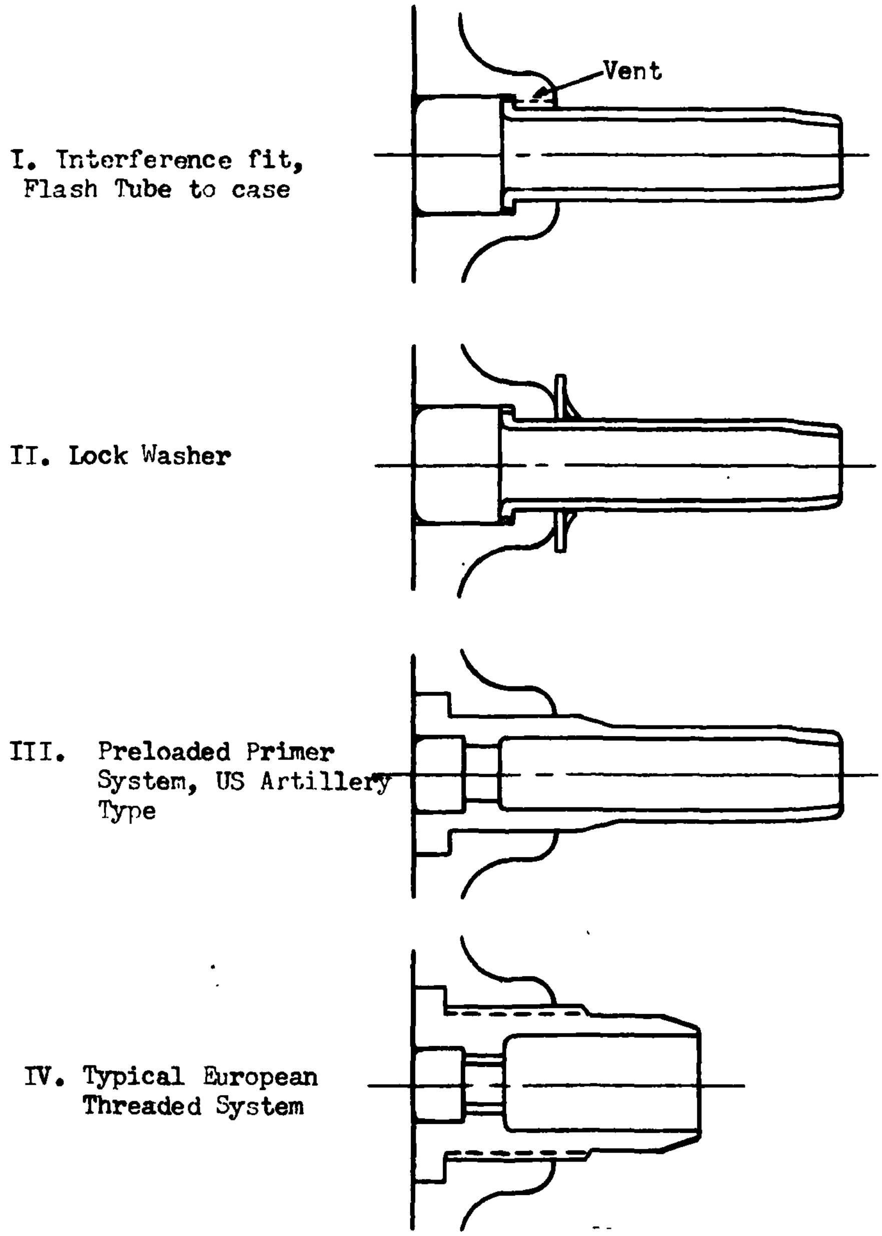


Figure 12. Potential Primer Systems Adapting GAU-8 Cases for NATO Applications

The third sketch is of a preloaded primer system, traditional in US artillery-type primer systems, with the primer and flash tube combined into a single assembly before pressing into the case. For the sake of comparison, the last view is of a European threaded primer system. The main objection to this system is the added cost of threaded components.

Links

In another investigation entailing use of the GAU-8 cartridge in the Oerlikon KCA gun, as used in the Swedish VIGGEN fighter, the effect of link damage to the case was investigated. Results are shown in Figure 13. Two links were investigated, the older 304 RK link and the current KCA link. Tests were conducted with the GAU-8 aluminum cases and with steel cases ranging in weight from 0.37 pound to 0.57 pound. Separate firing tests of cases with deepest link grooves showed no adverse effects from firings; the dented areas simply conformed to the chamber, without splits or tears. Cases were forced into and out of the links, then depths of dents were measured, and case volumes before and after pushing in and out of links were determined. With the current KCA link, and the preferred 0.51-pound case, link dent depth is about 0.018 inch in an area at the case shoulder. Plotted above is the effect of change in case volume produced by link damage, translated into the effect of height of propellant column. It is noted that for the 0.51-pound case, the propellant column is only raised by 0.005 inch. For the lighter case of 0.37 pound, this value is about 0.080 inch.

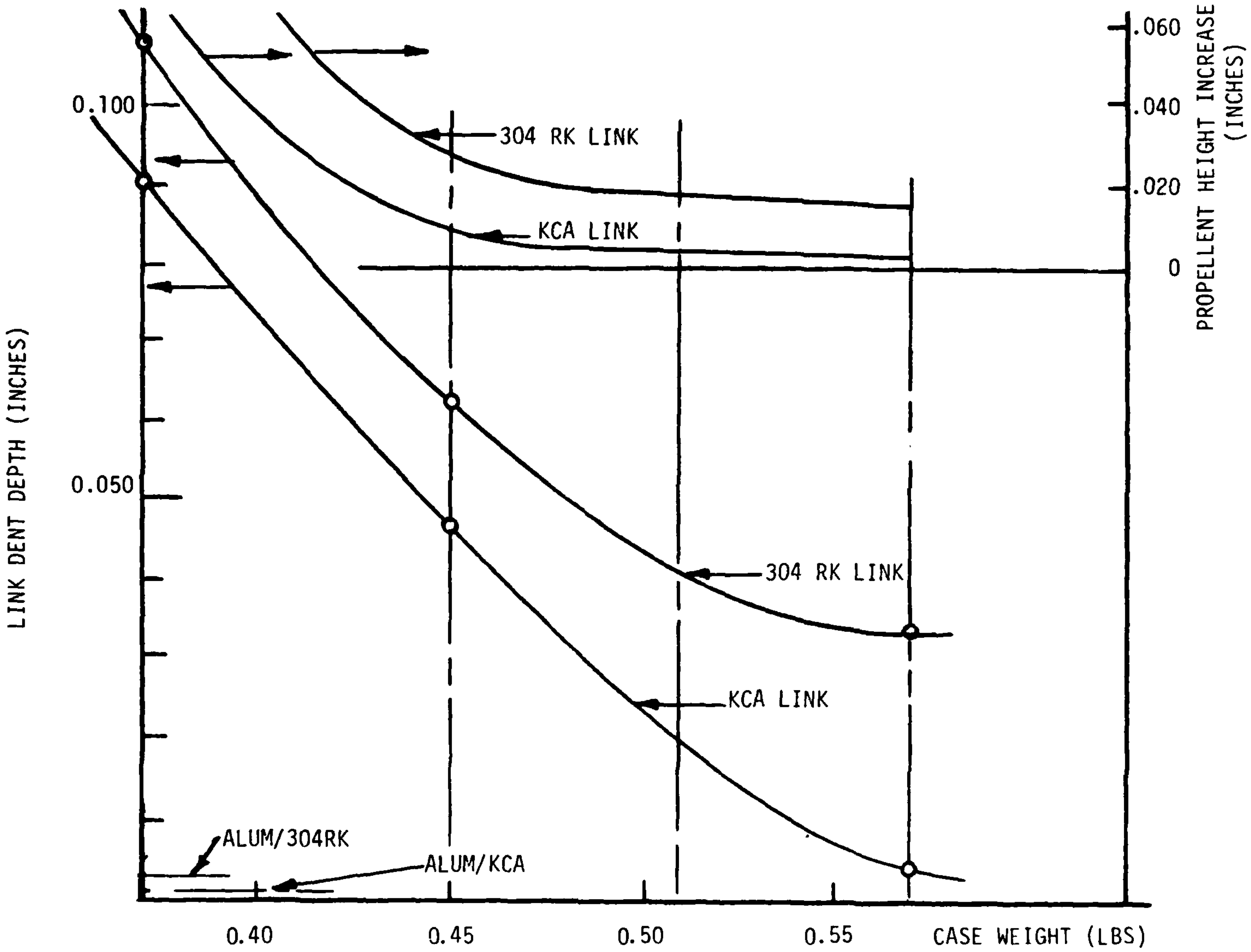


Figure 13. Link Damage Effects

SECTION III

PRODUCTION ANALYSIS

1. INTRODUCTION

This section identifies both development and production fabrication processes and techniques applicable to the 30mm GAU-8 thin-wall steel cartridge case. Approximately 1500 cases were completed during this contract period for five different case designs, each successively heavier. All were fabricated by a conventional rod, extrude, draw process. As the weight of the case increased, it became easier to fabricate. As one example, the number of mouth taper operations were reduced from 7 to 3. The final three designs were fabricated from rod which had been peeled to a surface depth of about 0.025 inch to remove seams present from the steel mill. This had the effect of appreciably reducing the scrap rate.

For the production cost analysis, the material cost for aluminum and steel for FY 79 and FY 81 are used to calculate unit material cost for the standard aluminum case and for the selected 0.51-pound thin-wall steel case. The direct labor is estimated from experience data for the aluminum case and from manpower estimates for the steel case. This results in roughly 15 percent more labor for the steel case.

By the fourth year into production, the assumption is made that all equipment and automation is installed, resulting in a savings per case of $0.421. Production rate is 250,000 per month on one shift, or 500,000 per month on two shifts. The assumed build-up rate is as follows:

FY	Percent of Automation	Number Per year	Cumulative Number Produced
1979	0	25,000	25,000
1980	10	250,000	275,000
1981	33	1,000,000	1,275,000
1982	63	4,000,000	5,275,000
1983	Full	6,000,000	11,275,000

2. CURRENT PROCESS DESCRIPTION

Given in Table 2 is the Operational Summary Sheet, Rod, Extrude, Draw, (RED), which describes the method used to fabricate the final lot of 250 of each of three designs, 0.51, 0.54, and 0.57 pound. Figure 14 depicts

TABLE 2. OPERATIONAL SUMMARY SHEET, ROD, EXTRUDE, DRAW (RED)

Operation No.	Operation Description	Machine Description
10	Receive and Check Order	
20	Receiving Inspection	
30	Saw Slug	Metal Saw
40	Pre-Anneal Wash	Metalwash (4) Stage/Dry
50	Anneal Slugs	Surface Combustion Anneal Furnace
60	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
70	Block	400-Ton Press
80	Pre-Anneal Wash	Ransohoff (7) Stage/Dry
90	Anneal	Surface Combustion Anneal Furnace
100	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
110	Extrude	400-Ton Press
120	Pre-Anneal Wash	Ransohoff (4) Stage/Dry
130	Anneal	Surface Combustion Anneal Furnace
140	Phosphate Lubricate and Dry	Ransohoff (7) Stage/Dry
150	Expand	400-Ton Press
160	Pre-Anneal Wash	See Opn. No. 40
170	Anneal	See Opn. No. 50
180	Phosphate Lubricate and Dry	See Opn. No. 60
190	Restrike	400-Ton Press
200	Pre-Anneal Wash	See Opn. No. 40
210	Anneal	See Opn. No. 50
220	Phosphate Lubricate and Dry	See Opn. No. 60
230	First Draw	135-Ton Press
240	Pre-Anneal Wash	See Opn. No. 40
250	Anneal	See Opn. No. 50
260	Phosphate Lubricate and Dry	See Opn. No. 60
270	Second Draw	135-Ton Press
280	Pre-Anneal Wash	See Opn. No. 40
290	Anneal	See Opn. No. 50
300	Phosphate Lubricate and Dry	See Opn. No. 60
310	Third Draw	100-Ton Press

TABLE 2. OPERATIONAL SUMMARY SHEET, ROD, EXTRUDE, DRAW (RED) (Concluded)

Operation No.	Operation Description	Machine Description
320	Third Draw Trim	Trimmer
330	Pre-Anneal Wash	See Opn. No. 40
340	Anneal	See Opn. No. 50
350	Phosphate Lubricate and Dry	See Opn. No. 60
360	Fourth Draw	100-Ton Press
370	Fourth Draw Trim	Trimmer
380	Indent and Head	400-Ton Press
390	Head Turn and Ream Flash Hole	Turret Lathe
400	Wash	Ransohoff (4) Stage/Dry
410	Harden (Brine Quench from 1625^{o}F)	Lindbergh Tube Furnace
420	Temper (650^{o} F)	Temper Oven with Belt
430	Body Anneal	Specially Designed Equipment
440	Pickle and Soap Coat	Ransohoff (4) Stage/Dry
450	Mouth Taper (3 Operations)	75-Ton Press
460	Final Trim	Lathe
470	Mouth Size	Arbor Press
480	Clean	Ransohoff (4) Stage/Dry
490	Phosphate	Specially Designed Equipment
500	Lacquer	Specially Designed Equipment
510	Final Inspection	
520	Pack and Ship	

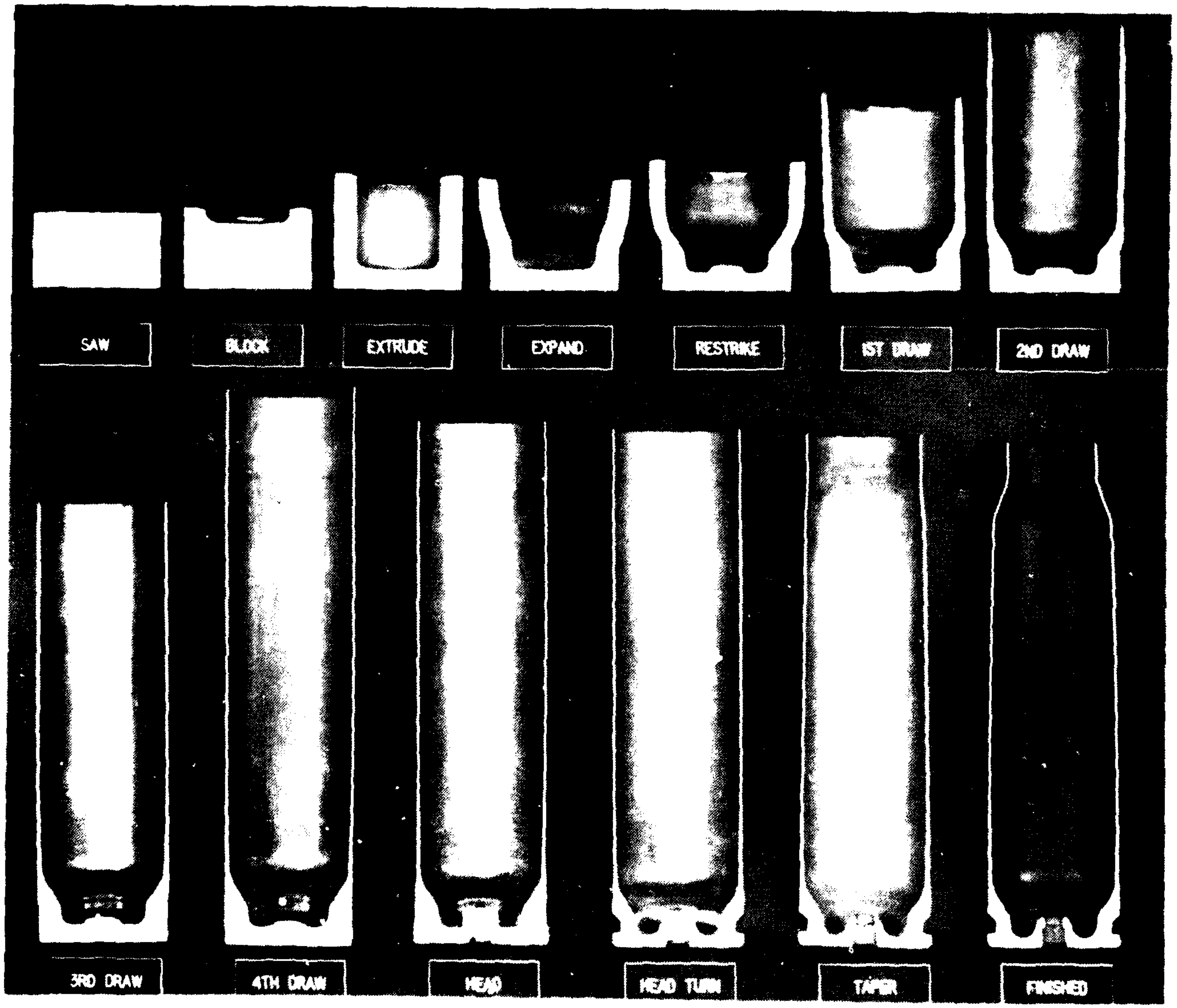


Figure 14. Operational Sequence of Case Fabrication

photographic sections of sequential mechanical case operations, while Table 2 includes all mechanical, thermal, and chemical operations, as well as final inspection, lacquering, painting, and shipping. The individual pieces of press tooling are generally similar to those planned for full production, but parts are hand-fed to the.press, and moved from press to press manually, instead of automatically. The chemical and thermal operations are nearly all carried out on production equipment.

The bars of 1-11/16 inches (1.685 inches) are peeled to a diameter of 1.634 inches at a subcontractor's facility and are sawed to length. After wash, anneal, phosphate, lubricate, and dry, the parts are blocked in the first mechanical press operation to a precise diameter and a shallow pocket is formed. After another anneal cycle, the extrusion operation is performed in a 400-ton press. To reach the shape required for drawing, two more press operations are required, each preceded by an anneal cycle. These operations are required to expand the interior cavity to a shape roughly approximating the final shape. These operations are designated "expand" and "restrike". The four draw operations are carried out in 100-ton or 135-ton presses, with intermediate anneal cycles. Each draw operation involves a punch carrying the part through two draw rings in tandem, one placed above the other. The last two draw operations are each followed by trim operations. An Indent and Head operation forms the interior primer boss, partially forms the exterior primer pocket, and moves metal to fill out the case rim.

In the head turning operation, the extractor groove, the primer pocket, and the flash hole are machined in a turret lathe (due to the small quantities involved). After washing, the case is hardened and tempered. Body anneal is carried out in a continuous line of gas burners. After pickle and soap coat, the mouth and body are tapered in three operations. After a final trim, the parts are mouth-sized. After cleaning, the parts go to final inspection. After application of phosphate and lacquer, the cases are ready to pack and ship.

3. PRODUCTION PROCESS CONSIDERATIONS

Considering a high rate production process, the case goes through essentially the same operations as previously described, but more efficient automated processes will be employed. Figure 15 depicts sketches of part shapes for three potential type processes from slug to ready for drawing. Type I is current. Type II substitutes a high speed precision shear machine for the saw and uses two extrusions involving successively smaller diameters instead of a single extrusion followed by two expanding operations. The steel is worked under compression for the major forming operations. The

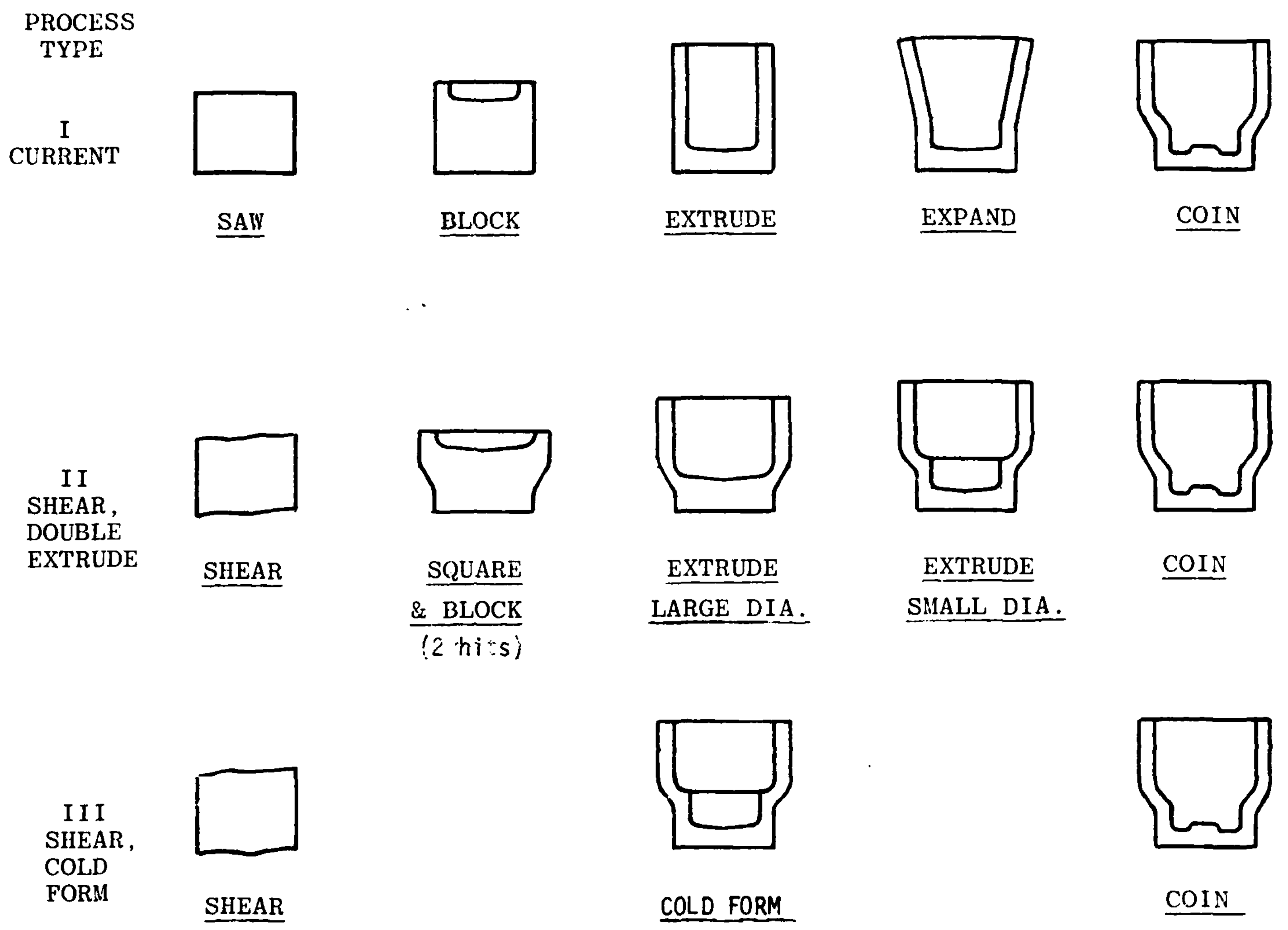


Figure 15. Future Production Process

square and block operations are done in a single press, but in two hits, to insure good concentricity. Type III substitutes a cold heading machine (5-stroke) to go from sheared slug to a part ready to coin in a single machine. The successive hits in a cold former cause the part to be warmed by the cold working and allows more cold working of the metal before annealing is required. However, it is possible that parts could be removed at an intermediate station and reinserted after annealing if required. At least two anneal cycles should be eliminated by use of the multi-station cold former.

For those conventional press operations retained, the press is automated by equipping it with a shuttle and providing automatic feed by hoppers and feeder bowls. The three taper operations are all done in a single press equipped with a rotary table. For head turning, the turret lathe is replaced by a high-speed automatic multiple spindle chucker. The final finishing processes of phosphating and lacquering employ automation to reduce manual handling of parts. After final draw operations, the parts are conveyed in an orderly, oriented position on conveyer systems with provisions for banking between operations rather than being handled in bulk in large hoppers or bins.

A system of patrol inspection is used to determine when to change tools for minimum down-time.

4. PRODUCTION COST COMPARISON

Estimates of production cost have been made to permit comparison of costs between the aluminum case and the thin-wall steel case.

Table 3 covers material calculations to permit direct material cost comparisons between the aluminum and steel cases. The upper section of Table 3 computes the aluminum material net cost per case, including the cost of the raw ingot currently government-furnished. A scrap rate of 4 percent is used, so the scrap value of the appropriate number of cases is reduced from the cost. Rings and turnings of reduced value are also computed. The cost of the basic 7475 aluminum bar is $1.25 per pound in FY 79, but this rises to $1.95 by FY 81. The net cost of material per delivered case at this stage in FY 81 is $0.828.

The steel scrap rate is assured to be 8 percent, based on experience in other steel case programs. This rate is valid only if the material is peeled to reduce scrap rate. The loss of material in peeling, the cost of the peeling, and additional shipping costs are all included in the final cost of the steel, shown as $0.3032 per pound in FY 79 and $0.3940 per pound in FY 81.

TABLE 3. MATERIAL CALCULATIONS

PRESENT ALUMINUM CASE (EXTRUDED FROM BAR)

RAW MATERIAL: Weight/Slug - 0.4109 lb.

SCRAP RATE: 4% CALCULATIONS:

$$\frac{1}{0.96} = 1.042;\ 1.042 \times 0.4109 = 0.428 \text{ lb/slug required}$$

SCRAP RETURN VALUE (PER FINISHED CASE)	0.318 solids x $0.210 x 0.04 scrap	= 0.0027
	0.093 rings, etc. x $0.11	= 0.0102
	Total Scrap Return	= 0.0129 (0.013)

		FY 79	FY 81
COST: 7475 Bar	0.428 lb x $1.25 (or $1.95)	$0.535	$0.835
(No GFM Ingot)	Less Scrap Return	0.013	0.013
FY 79 = $125/100 lb	NET ALUMINUM COST/CASE	$0.522	$0.822
FY 81 = $195/100 lb	Anodizing Material	0.006	0.006
	NET COST/CASE	$0.528	$0.828

THIN WALL STEEL CASE (EXTRUDED FROM BAR)

RAW MATERIAL: Weight/Slug = 0.730 lb

SCRAP RATE: 8% (8% Only if Hot Rolled Bar is Peeled to 0.030 Depth to Remove Surface Defects)

$$1.00 - 0.08 = 0.92$$

$$\frac{1}{0.92} = 1.087;\ 1.087 \times 0.730 = 0.794 \text{ lb}$$

Finished Case, Wt = 0.51 lb (solid scrap)
Rings, turnings, Wt = 0.220 lb

SCRAP RETURN VALUE (PER FINISHED CASE)	0.51 solids x $0.030 x 0.08 Scrap =	$0.00122
	0.220 Rings, etc. x $0.007 =	0.00154
	Total Scrap Return =	$0.002676 (0.003)

		FY 79	FY 81
COST: 10B22 Bar (Hot Rolled Peeled)	0.794 lb x $0.3032 (or $0.394)	$0.241	$0.313
	Less Scrap Return	0.003	0.003
	NET STEEL COST/CASE	$0.238	$0.310
FY 79 = $30.32/100 lb	Lacquering Material	$0.025	$0.025
FY 81 = $39.40/100 lb	NET COST/CASE	$0.263	$0.335

UNIT COST SUMMARY

	FY 79	FY 81
Aluminum Case	$0.528	$0.828
Steel Case	0.263	0.335
SAVINGS	$0.265	$0.493

NOTE: SAVINGS BEFORE GENERAL ADMINISTRATIVE AND PROFIT COST FACTORS

At the bottom of the figure, unit material cost per case is summarized as follows:

	FY 79	FY 81
Aluminum	$0.528	$0.828
Steel	0.263	0.335
Steel Savings	$0.265	$0.493

Shown in Table 4 is the production cost comparison of aluminum and thin-wall steel GAU-8 cartridge cases. Assumptions include fully automated lines for both aluminum and steel material costs on the FY 81 level and a production rate of 250,000 per month in one shift.

Hypothetical Cost Factors

Cost factors generally applicable to the Midwest for a multi-product (ferrous and non-ferrous) plant include a burden rate of 350 percent in FY 81 and a general, administrative and profit rate of 20 percent.

The cost analysis lists the savings in material of steel over aluminum from Table 3, and then enters labor and burden losses. After allowance for general administrative and profit costs, the net savings at selling price are $0.421 for the conventional RED process, or $0.444 for the RED process with cold former.

Assuming a rate of 500,000 per month, or 6 million per year, and use of the conventional RED process, saving $0.421 per case, the build-up of savings for successive years, to assess against non-recurring start-up cost , would be as follows:

Years Running Full Rate, After Reaching Full Automation	Total Savings (Millions)
1	2.53
2	5.05
3	7.58
4	10.10

Non-recurring costs for a completely new conventional RED line would be the order of $8,000,000, requiring 3 years to reach pay-back. For any new cartridge case, complete new lines are seldom required, but equipment availability is a function of many factors, such as status of stand-by lines, DIPEC equipment status, and availability of privately-owned equipment. Minimum new start-up cost should be appreciably less than $8,000,000 with well under 3 years to reach pay-back.

TABLE 4. PRODUCTION COST COMPARISONS FOR GAU-8 CASES

Rate of Production: 250,000 per month, one shift
500,000 per month, two shifts

Year of cost dollars: FY 81 (material and labor)

Cost Factors Assumed for Typical Plant, Fully Automated:

Burden: 350 percent

General Administrative and Profit: 20 percent

Cost Element	SAVINGS OVER ALUMINUM	
	Conventional RED	RED With Cold Former
Material	\$0.493	\$0.493
Labor and Burden (Loss)	-0.142	-0.123
At Works Delivery	\$0.351	\$0.370
At Selling Price (Add 20 percent)	\$0.421	\$0.444

For the RED process with cold former, non-recurring costs increase $1,250,000. In addition to unit cost savings of the order of $0.023, material handling requirements are reduced, and minimum decarburization is obtained through the elimination of two anneal cycles when the cold former is used.

SECTION IV. TEST RESULTS

1. INTRODUCTION

The purpose of this section is to summarize test results obtained throughout the development period. Propellant charges were established for two types of Hercules propellant, one for normal pressure and the other for excess pressure. Both gave good uniformity of pressure and velocity. As heavier cases evolved, with reduced interior volume, smaller charges were required. Normal Mann barrel tests showed no signs of case distress. However, automatic gun firings at Eglin continued to show transverse ruptures until case weights near one-half pound evolved. To shorten the development cycle, a flexible breech was developed, involving use of copper washers allowing sufficient crush-up to simulate automatic gun locking mechanism flexure. The flexible breech allowed duplication of the transverse ruptures observed in the automatic gun.

2. PROPELLANT PERFORMANCE

Shown in Table 5 are the test results at the start of the program leading to delivery by Hercules of 900 pounds of HC 25 Lot 26, blended at 58 percent - 5 percent deterrent coated and 42 percent - 2 percent deterrent coated. The added propellant volume, approximately 19 percent over that of the aluminum case, appeared to offer the potential of slightly over 200 fps muzzle velocity. The final case selected at the end of the program (Design "A", 0.51 lb) has 14 percent additional propellant volume, and will provide an increase in muzzle velocity of 150 - 200 fps.

Shown in Table 6 is a summary of the major propellant tests throughout the contract period. Pressure and velocity standard deviations are well within expected limits. For excess pressure tests, the 2 percent portion of a Hercules blend was increased until the desired pressure level was reached. Toward the end of the program a lot of 2 percent designated HC 25, Lot 906 was obtained which ranged between 2 and 3 percent deterrent coating, allowing nearly a full case with the straight 2 percent, avoiding the need for blending. With HC 25, Lot 26, some drop in pressure was observed when moisture level built up due to humid storage conditions. This lot did not contain a flash inhibitor, and this resulted in some losses of velocity measurements due to early triggering of velocity screens. Calibration of piezoelectric pressure gages at the end of the program indicated that pressures observed for the last group of three designs (0.51, 0.54, and 0.57 lb cases) were low by about 2,000 psi. The normal pressure Lot, HC 25, Lot 26, exhibited very little variation

TABLE 5. PROPELLANT TESTS

6642 Grain Projectile

	Eglin AFB	Amron	
Date of Test	Feb 77	Mar 77	Apr 77
Type Propellant	CIL 3532	2%,5%(1976) Hercules	2%,5%(1977) Hercules
Method of Loading	Bulk Dump No Vibration	Bulk Dump No Vibration	Bulk Dump No Vibration
Blend (at Test Site)	NA	74%:5% 26%:2%	57%:5% 43%:2%
Weight of Charge, Grains	2623	2800	2800
Peak Pressure, psi	56,800	56,000	56,500
Muzzle Velocity, fps	3430	3420	3402
Action Time, ms	NA	6.1	5.4

ROUGHLY COMPARABLE RESULTS WITH ALUMINUM CASES

	Muzzle Velocity
Bulk Dump, No Vibration	3180 fps
Vibration Tamped	3240 fps

TABLE 6. SUMMARY OF PROPELLANT TESTS
(All using 6644 Grain API Simulated Projectiles)

TYPE PROPELLANT	WEIGHT OF CASE (lb)	CHARGE (Grams)	NO. ROUNDS	TEMPERA-TURE	PRESSURE (psi)	PRESSURE SD (psi)	VELOCITY AT 78 FEET (psi)	VELOCITY SD (fps)
EXCESS PRESSURE								
45/55 (5%/2%)	0.37	183.7	19	Amb	63,820	570	3466	16
36/64 (5%/2%)	0.37	184.7	4	Amb	67,200	668	3379	30
36/64 (5%/2%)	0.37	184.7	9	Amb	66,530	735	3488	36
36/64 (5%/2%)	0.37	184.7	10	Amb	66,600	933	3443	59
36/64 (5%/2%)	0.37	184.7	10	Amb	63,800	730	3435	41
40/60 (5%/2%)	0.49	176.0	14	Amb	65,400	750	3458	16
40/60 (5%/2%)	0.45	176.0	7	Amb	65,040	-	3461	
37.5/62.5 (5%/2%)	0.45	181.5	--	Amb	70,000	-	-	-
HC25 Lot 906-2%	0.49	161.0	-	160°F	68,200	-	-	-
HC25 Lot 906-2%	0.49	161.0	-	Amb	65,200	-	-	-
HC25 Lot 906-2%	0.51(A)	159.0	-	Amb	65,000	-	-	-
HC25 Lot 906-2%	0.54(B)	159.0	-	160°F	66,900	-	-	-
HC25 Lot 906-2%	0.54(B)	159.0	-	Amb	65,000	-	-	-
HC25 Lot 906-2%	0.57(C)	159.5	-	160°F	67,190	-	-	-
HC25 Lot 906-2%	0.57(C)	159.5	-	Amb	65,000	-	-	-
NORMAL PRESSURE								
HC25 Lot 26	0.37	184	10	Amb	51,000	112	3345	6
HC25 Lot 26	0.37	184	20	+160°F	51,600	674	3315	7
HC25 Lot 26	0.37	184	20	-65°F	46,785	674	3312	10
HC25 Lot 26	0.45	176	4	Amb	54,250	-	3349	-
HC25 Lot 26	0.49	180	10	Amb	55,700	-	-	-
HC25 Lot 26	0.49	180	6	+160°F	54,970	-	-	-
HC25 Lot 26	0.49	180	6	-65°F	53,220	-	-	-
HC25 Lot 26	0.51(A)	179	-	Amb	56,000	-	-	-
HC25 Lot 26	0.54(B)	181	4	Amb	55,700	470	-	-
HC25 Lot 26	0.54(B)	181	4	Amb	55,800	220	-	-
HC25 Lot 26	0.54(B)	181	8	-65°F	55,600	1090	3399	12
HC25 Lot 26	0.57(C)	178	-	Amb	55,000	-	-	-
HC25 Lot 26	0.57(C)	178	-	-65°F	54,800	600	3371	4

Abbreviation SD = Standard Deviation

Note: Dashes indicate sample sizes were too small for significant statistical data, or in the case of velocities, loss of valid reading due to instrumentation problems.

with temperatures, and instances were noted where pressure actually dropped slightly in going from ambient to 165° F. Hercules indicated this was to be expected in this lot since some brittleness of the grain was present, and break-up of the grain was more inhibited at the higher temperatures.

Volume available for propellant, compared to the aluminum case, was computed as shown in Table 7 for the final three case designs.

TABLE 7. VOLUME COMPUTATIONS

		Thin-Wall Steel Cases		
Item	Alum.Case	A(0.51 lb)	B(0.54 lb)	C(0.57 lb)
Full Volume to Mouth (in^3)	10.496	11.78	11.70	11.595
Less Projectile Intrusion (in^3)	-1.37	1.37	-1.37	-1.37
Volume for Propellant (in^3)	9.126	10.41	10.33	10.225
Ratio, Steel Case Volume to Aluminum Case Volume		1.141	1.132	1.120
Percent Increase over Aluminum Case		14	13	12

3. MANN BARREL TESTS

General

The Phase II Mann barrel breech was provided with spacers for adjustment of head space. Local tests were normally conducted with spacers set for maximum head space. Action time was measured, and values generally ranged between 3 and 6 milliseconds, exerting no influence on the thin-wall case design but serving to indicate that the primer system was functioning properly. At excess pressure levels, it was useful to determine the force required to extract the case from the chamber. This was done by means of a T-slot type fixture with a bolt and nut and a torque wrench. The torque wrench was calibrated to permit translation from torque in foot-pounds to pounds force. Excess loads on the fixture threads occasionally required rework and recalibration of the fixture. Besides the tests reported in the propellant performance subsection and flexible breech tests subsections, various other Mann barrel tests were conducted and are reported in this subsection.

Case Extraction Forces

Tests in August 1977 of 0.51-lb cases for extraction forces as a function of finish and hardness were as follows:

Type Coating	Mean Maximum Pressure (psi)	Mean Extraction Force (lb)	Hardness (R30N)
DeBeers (Blast)	67,200	685	58.5
Mader/No Blast	66,530	1171	58.5
Mader/Blast	66,660	1337	58.5
Mader/Blast	63,820	1654	56

The tests indicated that case extraction is higher with the Mader finish than with DeBeers, due to higher coefficient of friction.

The glass bead blasting of the surface gave slightly improved cosmetic appearance to the case finish but increased the extraction force. Since the blasting operation also added cost, it was dropped from subsequent processing operations.

The softer cases gave increased extraction force due to the tighter interference fit after pressure decay.

Figure 6 from the section on Design Analysis compares aluminum cases with Mader and DeBeers coated cases as to case extraction forces, indicating the aluminum case to be intermediate between thin-wall steel cases with Mader finish (higher extraction force) and cases with DeBeers 30 percent Teflon® finish (lower extraction force).

Test results conducted on 0.37-pound cases in 1977 for case extraction forces are plotted in Figure 16. Besides the effect of higher extraction forces for the Mader lacquer, the plot also brings out the effect of lower strength (lower hardness) in increasing case extraction force, whether the coating is Mader lacquer or DeBeers lacquer.

In local tests of the final three designs at excess pressure of 67,000 to 68,000 psi, the following extraction forces were observed:

Case Design	Extraction Force (lb)	
	Mader	DeBeers
"A" (0.51 lb)	900	600
"B" (0.54 lb)	1200	600
"C" (0.57 lb)	1100	650

The thinner walled cases generally had lower extraction forces. The selected case design, type "A", 0.51 lb with Mader finish, showed an acceptable 900-pound case extraction force.

Excess Head Space Tests

In November 1977 at Eglin Air Force Base an excess pressure test of 70,000 psi, coupled with a worn automatic gun with excess head space and use of an oiled case resulted in a blow-out at the unsupported case head. The case was redesigned, with about 30 percent increased wall thickness under the extractor groove, as apparent from the case sections shown in Figure 1. Tests were conducted for the reinforced case in the Mann barrel with an excess pressure charge, at excess head space increments of 0.020 inch per shot. To avoid misfires, it was necessary to force the case to the rear by means of a cardboard collar at the neck. Results were as follows:

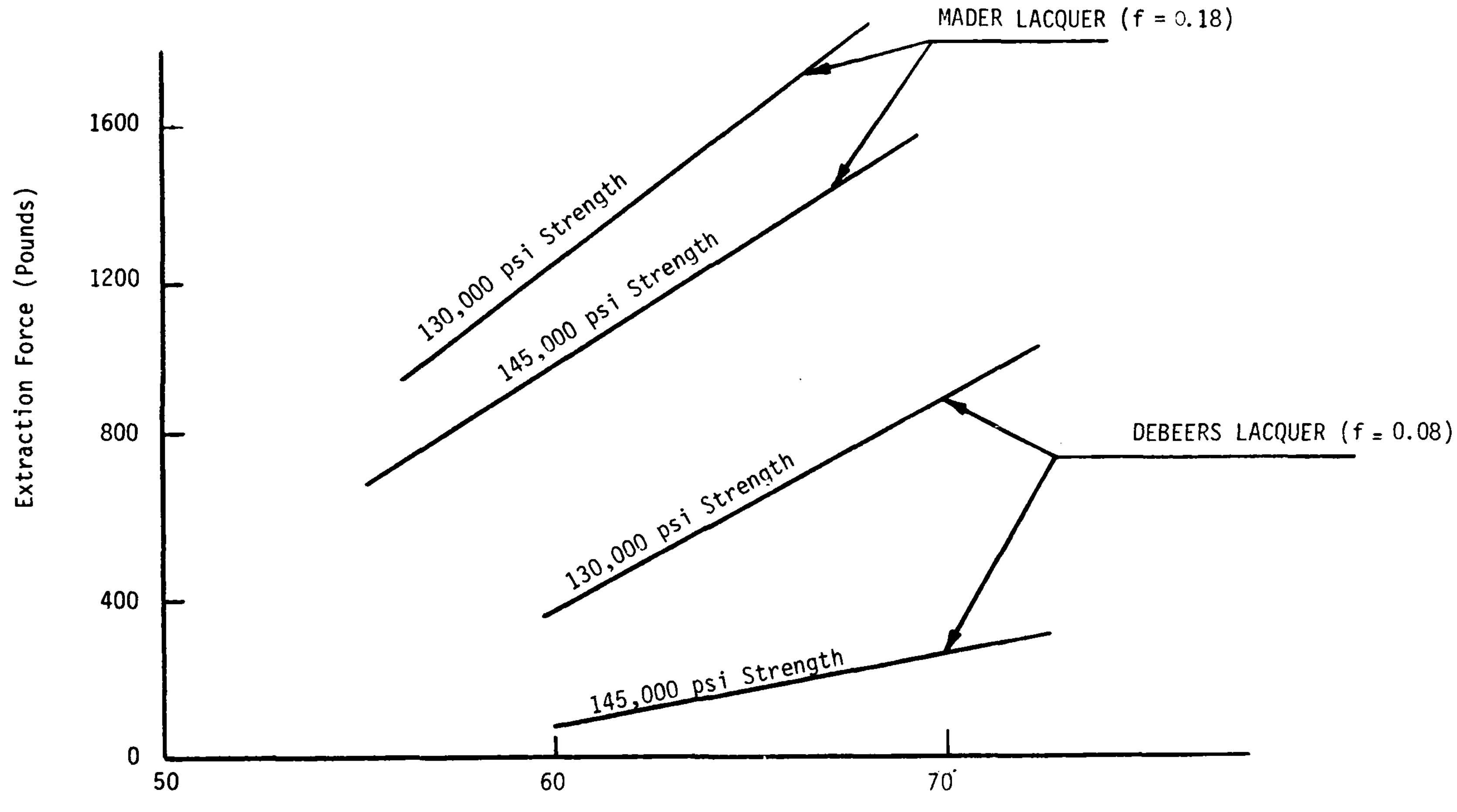


Figure 16. Case Extraction Forces with Varying Strengths

Excess Head Space (in)	Pressure (psi)	Excess Growth* (in)
0.020	65,000	0.001
0.040	63,700	0.003
0.060	54,600	0.003
0.080	61,300	0.004
0.100	60,800	0.009
0.120	59,400	0.009

* Excess growth measured 0.060 inch forward of extractor groove.

There was no case rupture, even with excess head space up to approximately one-eighth of an inch.

4. BULLET PULL TESTS

Shown in Table 8 is a summary of the bullet pull test results throughout the program. The criterion for passing bullet pull tests is primarily that mean pull less three standard deviations be greater than 1800 pounds. Another criterion was for no pull under 1900 pounds. The low pulls throughout the earlier testing, involving 0.37-pound cases, were primarily due to a worn ring in the Detroit Tester. Before the worn ring was replaced, the softer mouth cases gave better results, since they crimped deeper with the worn ring, but no large sample was satisfactory. With replacement of the ring, mouths hard or soft gave mean pulls in the 2400- to 2500-pound range. Then problems with surface coatings arose. Cases with interior black lacquer over light phosphate as corrosion protection did not allow proper action of the Loctite sealant, and low bullet pull resulted. A few cases with zinc plate, without chromate conversion were tried, and the zinc appeared to act as a lubricant, giving low pulls. It was concluded that phosphate treatment alone in the interior offered sufficient corrosion protection and that spillover of exterior lacquer into the case mouth influenced pull, with Mader-coated cases (higher friction) giving better pull than DeBeers 30 percent Teflon® coated cases (lower friction).

Limitations on number of design "A" cases restricted the test number to 3, and these results were influenced by adjustments being made to the mouth sizing tool. However, wall thickness is essentially the same for all three designs, and the 40 cases tested for the "B" and "C" type cases, 20 with Mader, and 20 with DeBeers should also apply to the type "A" case. Mean pulls less three standard deviations were 2739 pounds and 2691 pounds for these two designs, against a requirement of 1800-pound minimum. Therefore, bullet pull should be easily met with the design selected, type "A", 0.51 lb, with Mader finish.

TABLE 8. SUMMARY OF BULLET PULL RESULTS
(Single Groove, GFE-API Simulators, Lot AJD-40-1-76)

Case Type	Mouth Wall Thickness (in)	Mouth Hardness KHN	No. Tested	Mean Pull (lb)	Standard Deviation (lb)	Mean Less 3 Standard Deviations (lb)
0.37 lb (re-used)	0.018	304	6	1377	157	906
0.37 lb (re-used)	0.018	274	2	1600	-	-
0.37 lb (re-used)	0.018	231	33	2500	-	-
0.37 lb	0.018	231	5	2170	-	-
0.38 lb	0.019	231	5	1991	-	-
0.38 lb	0.019	301	15	1799	226	1122
0.38 lb	0.019	188	15	1718	-	-
0.38 lb	0.019	241	7	1915	103	1606
0.38 lb	0.019	241	8	1969	285	1114
Worn crimp ring in Detroit Tester replaced						
0.38 lb	0.019	304	10	2443	142	2017
0.45 lb	0.021	237	15	2481	139	2064
0.45 lb (partial cure)	0.021	237	6	2105	81	1863
0.48 lb (int. paint)	0.022	231	5	1576	-	-
0.48 lb (int. paint)	0.022	260	5	1732	-	-
0.48 lb (DB out)	0.022	260	3	2450	-	-
0.48 lb (M out)	0.022	260	3	2910	-	-
0. 48 lb (M out)	0.022	260	4	2680	-	-
"A" (0.51 lb) (M)	0.027	266	3	2433	-	-
"A" (0.51 lb) (DB)	0.027	266	3	2087	-	-
"B" (0.54 lb) (M)	0.027	252	10	3276	179	2739
"B" (0.54 lb) (DB)	0.027	252	10	2180	54	2018
"C" (0.57 lb) (M)	0.027	264	10	3092	147	2691
"C" (0.57 lb) (DB)	0.027	264	10	2222	59	2045

Abbreviations: M = Mader Lacquer; D = DeBeers Lacquer
Note: Dashes indicate the sample size is too small to determine significant statistical values, or other variables are present within the number tested.

5. FLEXIBLE BREECH TESTS

General

Of the various thin-wall design areas requiring attention, the most chronic problem area was the occurrence of transverse ruptures, occurring only in the automatic gun, never in a Mann barrel. On completion of the March 1978 normal and excess pressure tests at Eglin Air Force Base of the latest 0.45-lb design, the problems seemed to have been solved, but in April, transverse ruptures again occurred when DeBeers coated cases at excess pressure hot were fired immediately after a seven-round burst of cold normal pressure rounds, which appeared to frost the chambers. The contract was modified to permit remaining funds to be applied to the design of three successively stronger cases, each of which was to pass a flexible breech test developed by the contractor to simulate the stretching action of the automatic gun.

The first flexible breech design used four aluminum rods to serve as permanent compressible springs to allow the order of 0.018-inch compression to occur before a pressure plate bottomed-out on the long supporting breech block. One was built, but two problems developed. The rods were too "bouncy," and this offered problems in measuring deflection under load. The electric firing pin was difficult to insulate in a manner to provide suitable life for insulation components.

Investigation of prior work in 20 mm size led to the background of effort with aluminum cases several years ago to apply flexible breech techniques by use of copper washers made from 3/4-inch extra heavy annealed copper tubing. This concept was applied to the 30mm GAU-8 successfully. A flight weight barrel with breech block was provided by Eglin Air Force Base. Shown in Figure 17 is the modification carried out on on that breech block. The entire bottom face of the breech cavity was counter-bored 0.019 inch below the original face. Then a groove 0.084-inch deep was machined to accept a copper washer 0.115-inch thick. To give proper hardness to the copper washer, rings of annealed copper 0.171-inch thick were turned from the copper tubing. Inside and outside diameters of the tubing were 0.738 inch and 1.047 inches, respectively. Figure 18 shows two load deflection traces; the one on the left is the cold working operation of pressing the annealed washer to a fixed stop 0.115-inch thick, with the load of 31,000 pounds recorded for a deflection of 0.061 inch. The trace on the right is a calibration curve of one of the 0.115-inch washers, indicating that for the then expected set-back load of 52,000 pounds, the deflection would be 0.024 inch. The actual load turned out to be of the order of 75,000 pounds for pressures of 71,000 psi, at a

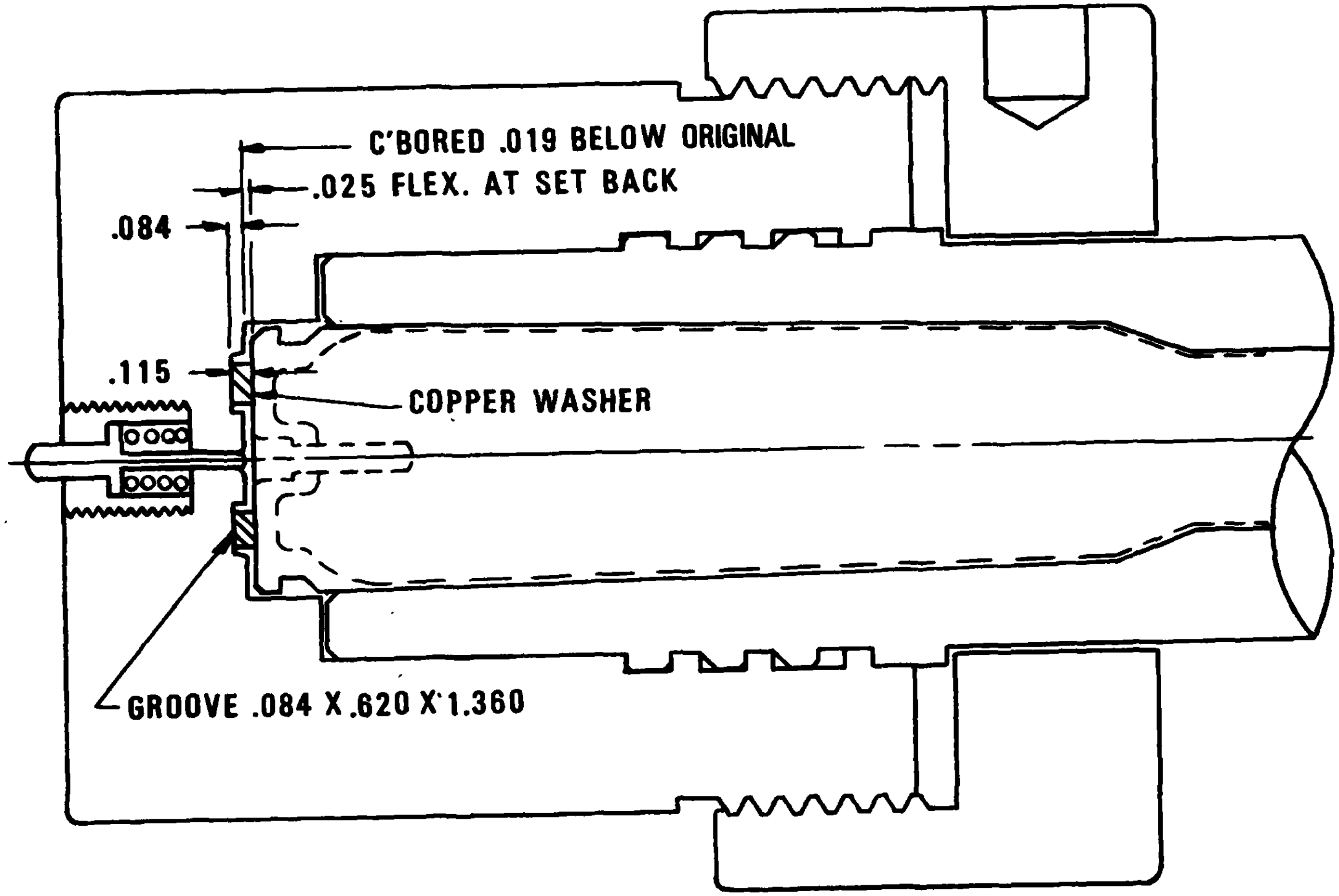


Figure 17. Modified Flight Weight Barrel Breech Block

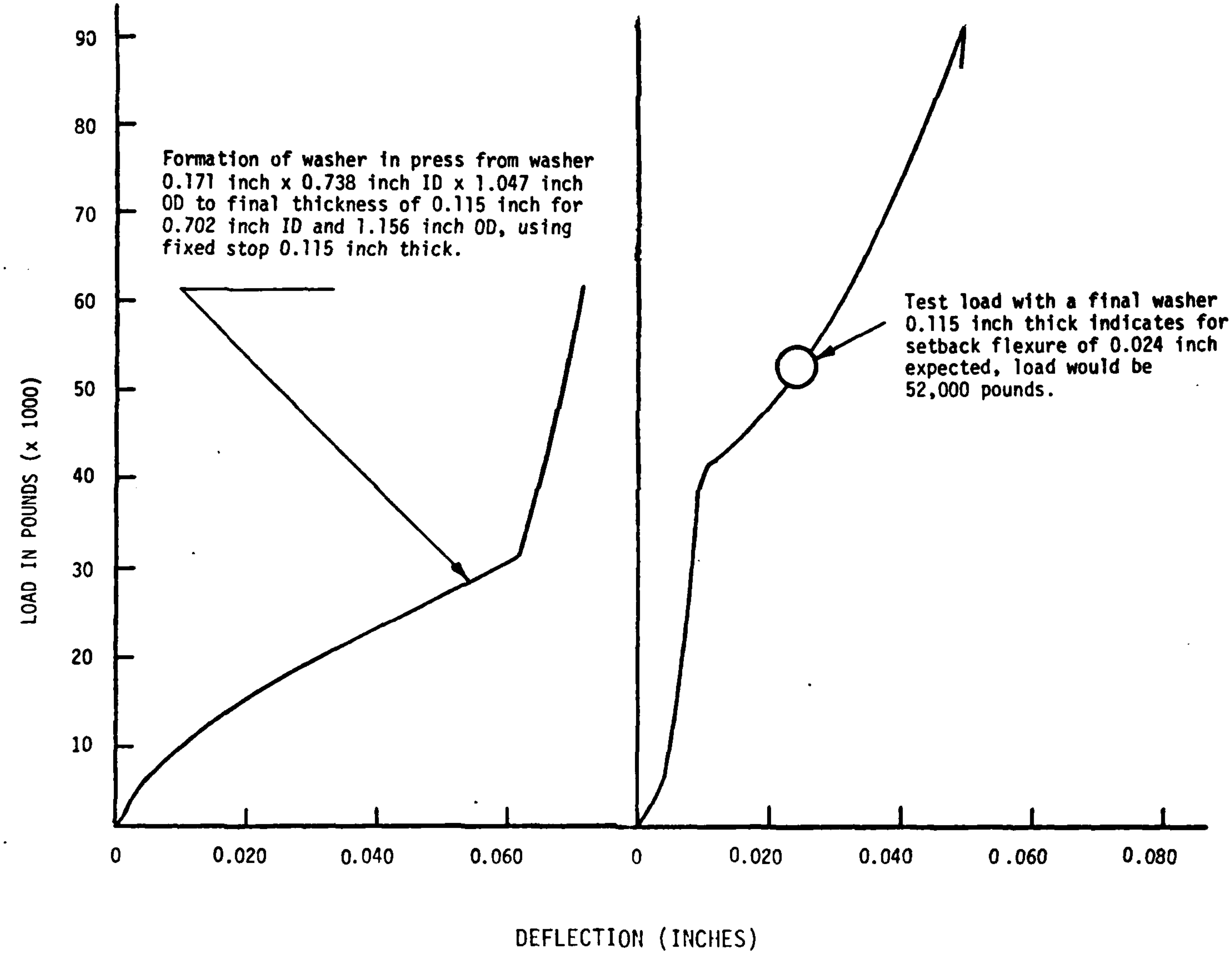


Figure 18. Load versus Deflection for Copper Washer

set-back flexure of 0.040 inch. With the breech of Figure 17 modified to allow only 0.025 inch, actual flexures of the order of 0.033 inch occurred by further deflection of the adjacent breech face flange contacted by the head of the case. Of three flexible breech degrees of severity, this procedure with the modified flight weight barrel offered the greatest stretch, and this test condition was rated "extreme". Initial tests of 0.45-pound DeBeers coated cases, of the type which failed in the automatic gun in April 1978, showed no damage. However, with oil applied lightly to the rear 2 inches of the case, a complete rupture was obtained. This then led to a procedure of moistening the rear of the case by dipping in water 2 inches deep to simulate the moisture from frosted cases, leaving a residue of moisture in the chamber. Tests with a frosted round indicated the entire chamber held droplets of moisture initially; in 5 minutes the front half was dry, and in 15 minutes the entire chamber was dry. With the "wet" test, the 0.45-lb case DeBeers coated also completed separated. By now, the heavier design case was available, weighing at that time 0.48 pounds, but destined to become the successful 0.51-pound type "A" design. Shown in Figure 19 are three cases tested in this manner in "wet" tests of 71,000 psi pressure. On the left is a Mader coated 0.48-lb case, which suffered no rupture or even stretch marks. In the center is a standard aluminum case which experienced a partial rupture. On the right is a 0.48-lb DeBeers coated case showing a complete separation, in the same manner as the 0.45-lb DeBeers coated case. In order to identify the added strength of the 0.48-lb case over the 0.45-lb case, it was necessary to develop two more orders of test severity. These were found relatively quickly by cementing either a 0.020-inch thick annealed washer or 0.036-inch thick washer to the base of a case, and firing in the Mann barrel, with the breech extra spacers added to allow either 0.030 inch or 0.040 inch extra head space. Such washers were cut from the same basic annealed copper tubing of 3/4-inch extra heavy size. These two test conditions were designated "moderate" for the 0.020-inch washer and "severe" for the 0.036-inch washer, all with 71,000 psi maximum pressure, and "wet" with 2 inches of water. Exploratory tests indicated at least 5 levels of distress: no damage, severe stretch, light partial rupture, severe partial rupture, and rupture. By selecting a test which allowed the distress level to avoid the extremes (no damage or rupture), a system of ranking could be established to rate one case design or one case finish against another to evaluate designs before submission for Eglin automatic gun tests.

A series of tests covering 42 cases including three designs (0.45-lb and 0.48-lb thin-wall steel, and standard aluminum) and three thin-wall steel finishes (Mader, DeBeers, zinc) was conducted, and these results are summarized in Table 9. From the data in Table 9, it was concluded that relative order of case strength in resisting transverse rupture is as follows:

Figure 19. GAU-8 Flexible Breech Case Ruptures

TABLE 9. SUMMARY CASE STRETCH TESTS

	Test Condition	Case Design (lb)	Coating	No. Tested	No Damage	Severe Stretch	Light Partial Rupture	Severe Partial Rupture	Rupture
1	Extreme(C)	0.48	Mader	2	2				
2	Extreme	Alum	Anodized	3		2		1	
3	Extreme	0.48	DeBeers	2				1	1**
4	Extreme	0.45	DeBeers	1					1
		Subtotal		8					
5	Severe(A)	0.48	Mader	5	5*				
6	Severe	0.45	Mader	2	2				
7	Severe	Alum	Anodized	2		1	1**		
8	Severe	0.48	Zinc	2				1	1
9	Severe	0.48	DeBeers	4				3	1
10	Severe	0.45	DeBeers	2					2
11	Severe	0.45	Zinc	2					2
		Subtotal		19					
12	Moderate(B)	0.45	Mader	1	1				
13	Moderate	0.48	DeBeers	5	1	4**			
14	Moderate	0.45	DeBeers	4			3	1	
15	Moderate	0.48	Zinc	1				1	
16	Moderate	0.45	Zinc	1				1	
		Subtotal		12					
		Total		39 (42, including dry and oiled comparative tests)					

* On another case tested, but with oil instead of water, mild stretch was noted.
** Similar case tested, but dry instead of wet base, no damage.

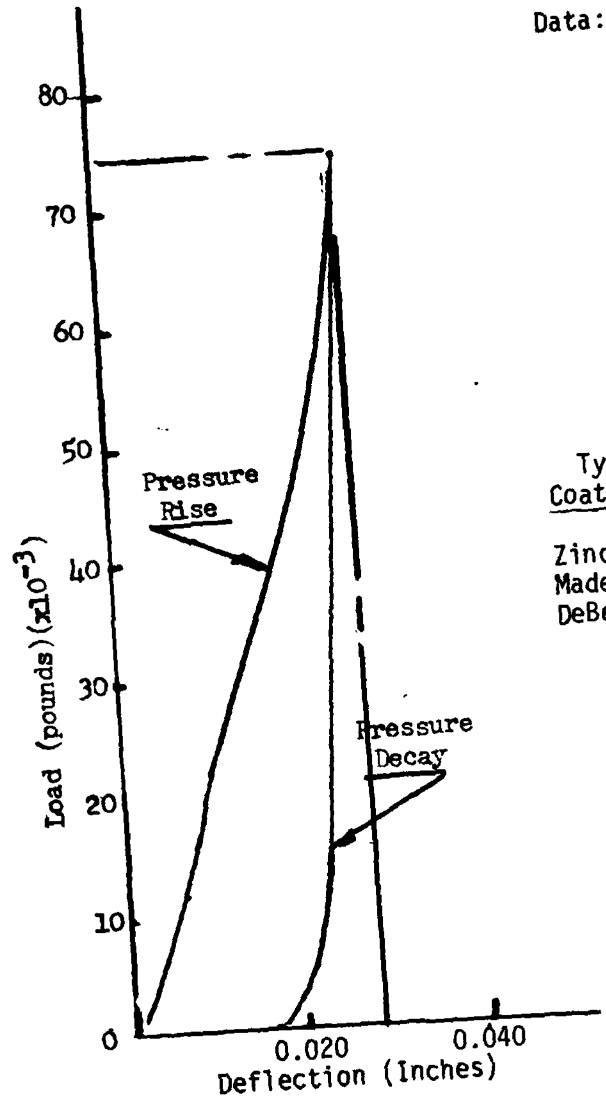
Test Conditions	Barrel	Pressure (psi)	Excess Head Space (in)	Copper Washer Size (in)	Case Base Surface (wet or dry)
Moderate(B)	Mann	70,000	0.030	0.020	Wet
Severe(A)	Mann	70,000	0.040	0.036	Wet
Extreme(C)	Flight Wgt.	70,000	0.010	0.115	Wet

1.	Mader Coated	0.48-lb Design (Best)
2.	Mader Coated	0.45-lb Design
3.	Aluminum Case	Standard
4.	DeBeers Coated	0.48-lb Design
5.	DeBeers Coated	0.45-lb Design
6.	Zinc Coated	0.48-lb Design
7.	Zinc Coated	0.45-lb Design

An off-shoot of data from use of the copper washer flexible breech system is shown in Figure 20. Calibration of the 0.036-inch copper washer in a manner similar to the procedure for the 0.115-inch washer of Figure 19 was carried out. The load deflection data for the fired 48-lb DeBeers coated case is plotted, providing data such as peak force: 75,000 pounds, peak deflection: 0.28 inch. Similar data from other tests is listed at the end of Figure 21 for various coatings. Zinc shows the greatest friction level at 90,000 pounds, Mader next at 83,000 pounds, and DeBeers last, at 77,000 pounds.

Shown in Table 10 is the summary of similar results for 23 cases, including two aluminum cases, case Design types "A", "B", and "C", and two finishes, Mader and DeBeers. Note that only two test conditions are used: extreme and severe. The moderate test was not needed as cases became stronger. Combining the data of Tables 8 and 10, relative resistance to rupture can be rated against any desired reference case. Table 11 uses two reference cases: the 0.45-lb DeBeers coated case, which failed Eglin "wet" tests, and the standard aluminum case. All designs are superior to the 0.45-lb DeBeers case except zinc coated 0.45-lb and 0.48-lb cases. Designs superior to the standard aluminum case include all Mader coated cases (0.45-lb, 0.48-lb, "A", "B", and "C" designs), and the DeBeers coated "B" and "C" designs. Only the DeBeers coated 0.45-lb, 0.48-lb, and Design "A" cases, and zinc coated 0.45-lb and 0.48-lb cases are inferior to the aluminum case.

After completion of the automatic gun tests summarized in the next section, stretch marks in some cases, about one inch from the base, were the only observed distress areas in any of the cases tested, and these were least for Design "A" and worst for Design "C". These results raised the questions of whether the flexible breech tests could have been more comprehensive and possibly have predicted the Eglin results. The procedure would involve wetting cases at distances from the base of 1 inch, 1-1/2 inches, and 2 inches instead of only at 2 inches.



Data: Type Case-Thin Wall 0.48-lb Design, DeBeers Coated
Maximum Pressure: 71,500 psi
Excess Head Space: 0.040 inch (above Maximum)
Original Thickness Annealed Copper Washer: 0.036 inch
Case Lubricant: Moisture, rear 2 inches

Final Copper Thickness: 0.018 inch
Maximum Copper Deflection: 0.028 inch
Maximum Load on Copper Washer: 75,000 pounds

Type Coating	Maximum Deflection (In.)	Maximum Load (Lb)	Friction* Load (Lb)	Change in Case Length (In.)
Zinc Plate	0.023	62,000	90,000	NA (Separated)
Mader	0.026	69,000	83,000	-0.012
DeBeers	0.028	75,000	77,000	+0.022

* Based on peak internal gas pressure force of 152,000 pounds.

Figure 20. Load Deflection for 0.036-Inch Copper Washer

TABLE 10. SUMMARY OF "A", "B", AND "C" CASE STRETCH TESTS

Test Condition	Case Design	Coating	No. Tested	No. Damaged	Severe Stretch	Partial Rupture	Complete Rupture
Extreme	A	Mader	4	4			
Extreme	A	DeBeers	1				1
Extreme	B	Mader	5	5			
Extreme	B	DeBeers	2	2			
Extreme	C	Mader	5	5			
Extreme	C	DeBeers	3	3			
Extreme	Alum.	Anodized	2		2		
Severe	A	DeBeers	4		1	3	
Severe	B	DeBeers	3	3			
Severe	C	DeBeers	2	2			

TABLE 11. RELATIVE RESISTANCE TO RUPTURE

Reference Case	Superior Resistance	Inferior Resistance
0.45 lb. DeBeers*	Mader 0.45 lb, 0.48 lb (Best) Mader A, B, C DeBeers 0.48 lb DeBeers A, B, C	Zinc Coated 0.45 lb, 0.48 lb
Standard Aluminum	Mader 0.45 lb, 0.48 lb (Best Mader A, B, C DeBeers B, C	DeBeers 0.45 lb, 0.48 lb DeBeers A Zinc Coated 0.45 lb, 0.48 lb (worst)

*Case which failed at Eglin AFB in April 1978 in hot high pressure tests following cases tested at -65 degrees F.

Toward this end, flexible breech tests were conducted on 8 November 1978, as shown in Table 12, in the same manner as for extreme level of "wet" tests, except depth of water is changed from 2 inches to 1 inch, and for 2 shots, the rear of the case is lightly oiled for 1 inch. A Design "C" case with DeBeers finish showed severe stretch, where no damage had occurred for 2-inch wetting. Design "A" with Mader showed no stretch marks. Using oil as a more severe test media and placed over the rear inch of "B" and "A" design cases, Mader coated, a deep groove occurred in the "B" design case, but only a shallow one in the "A" design case. The conclusions of these tests are as follows:

1. Flexible breech tests can be designed to back up automatic gun tests.

2. Design "C" with DeBeers is inferior to Design "A" with Mader.

3. Oil instead of water for lubrication increases test severity.

4. Design "A" with Mader lacquer is preferred.

In summary, the flexible breech tests closely simulate automatic gun testing in determining resistance to rupture. However, such tests accurately predicted that Mader coated cases would fare better than DeBeers coated cases and that Designs "A", "B", and "C" would not rupture, regardless of finish, and they did not. With a minor extension of testing for more than one depth of wetness, flexible breech tests could probably have predicted the unexpected result of Design "A" being superior to Designs "B" and "C".

6. AUTOMATIC GUN TESTS

A brief synopsis of major automatic gun test results at Eglin Air Force Base during the program for various designs is shown in Table 13.

The earlier tests with lighter cases indicated that minor changes would not serve to correct transverse ruptures. The 0.45-lb case might have been successful if only Mader coating were used. The 0.51-lb Type "A" design with Mader coating meets all tests and is the preferred design.

Shown in Table 14 are the results of thin-wall automatic GAU-8 gun tests at Eglin Air Force Base on 1 and 2 November 1978. Variables included two firing rates, two pressure levels, three temperatures, and special "wet" tests. There were three basic case designs, "A", "B", and "C", as well as a few 0.45-lb cases. There were two finishes. Of the number tested on each line, other columns identify the number satisfactory or the number with stretch marks one inch from the base, either inside or outside the case. The last column identifies, for those lines where stretch was observed, the depth of the stretch groove on the inside for the deepest stretch observed. Depth of stretch grooves up to 0.008

TABLE 12. FLEXIBLE BREECH TESTING

Design	Finish	Lubrication	Groove Depth at 1-1/4 Inches
C (0.57 lb)	DeBeers	1 in. Water	0.006 (at t_w = 0.049)
A (0.51 lb)	Mader	1 in. Water	0 (at t_w = 0.043)
B (0.54 lb)	DeBeers	1 in. Water	0.014 (at t_w = 0.042)
A (0.51 lb)	DeBeers	1 in. Oil	0.002 (at t_w = 0.038)

TABLE 13. SUMMARY OF AUTOMATIC GUN TEST RESULTS

Case Design	No. Shipped	Test Results
0.37-lb, Mader	300	Transverse cracks and stretches, mainly at excess pressure or hot nominal pressure.
0.37-lb, Mader	84	No significant improvement with variables such as head to datum length, lacquer thickness, or improved punches. One oiled case, loaded for excess pressure, blew out at unsupported head.
0.45- lb Mader, DeBeers	70	No casualties, normal or excess pressure, or at low temperature. At excess pressure hot, following cold wetting controls, 4 of the 7 DeBeers coated cases ruptured.
"A", "B", "C" (0.51, 0.54, 0.57 lb) Mader, DeBeers	354	No casualties, any test conditions, including "wet" tests. No stretch marks in "A" cases, Mader coated, in standard dry tests. In wet tests, minor stretch marks, no more severe than for aluminum cases. Stretch marks were more evident in DeBeers coated cases and in "B" and "C" designs. Preferred: The Design "A" Mader coated.

TABLE 14. SUMMARY OF FINAL AUTOMATIC GUN TESTS NOVEMBER 1978

Rate	Pressure	Temperature	Design	Finish	No. Tested	No. Satis factory	No. Stretched 1 Inch from Base	Maximum Stretch Groove Depth (In.)
L	Norm.	Amb.	A,B,C	M,D	42	42	0	0
L	Norm.	Cold	A,B,C	M,D	42	42	0	0
L	Norm.	Hot	A	M,D	14	14	0	0
L	Norm.	Hot	B	M	7	7	0	0.004
L	Norm.	Hot	B	D	7	1	6	0.002
L	Norm.	Hot	C	M	7	0	7*	0.011
L	Norm.	Hot	C	D	7	0	7	0.004
H	Norm.	Hot	A	M	7	7	0	0
H	Norm.	Hot	A	D	7	4	3	0.003
H	Norm.	Hot	B	M	7	0	7	0.007
H	Norm.	Hot	B	D	7	0	7	0.005
H	Norm.	Hot	C	M	7	0	7	0.006
H	Norm.	Hot	C	D	7	0	7	0.005
L	Exc.	Amb.	A	M,D	14	14	0	0
L	Exc.	Amb.	B	M	3	3	0	0
L	Exc.	Amb.	B	D	3	1	2	0.004
L	Exc.	Amb.	C	M	7	5	2	0.002
L	Exc.	Amb.	C	D	7	0	7	0.005
H	Exc.	Amb.	A	M	7	7	0	0
H	Exc.	Amb.	A	D	7	6	1	0.001
H	Exc.	Amb.	B	M	7	5	2	0.005
H	Exc.	Amb.	B	D	7	1	6	0.003
H	Exc.	Amb.	C	M	7	4	3	0.007
H	Exc.	Amb.	C	D	7	2	5	0.005
L	Exc.	Amb.	.45	M	7	5	2	0.001
L	Exc.	Amb.	.45	D	7	6	1	0.001
L	Exc	Amb. (Wet)**	A	M	6	3	3	0.002
L	Exc.	Amb. (Wet)	A	D	6	1	5	0.003
L	Exc.	Amb. (Wet)	B	M	6	0	6	0.009
L	Exc.	Amb. (Wet)	B	D	6	0	6	0.009
L	Exc.	Amb. (Wet)	C	M	6	2	4	0.007
L	Exc.	Amb. (Wet)	C	D	5	0	5	0.014
L	Exc.	Amb. (Wet)	.45	M	6	4	2	0.006
L	Exc.	Amb. (Wet)	.45	D	6	4	2	0.003

*1st Burst after cold tests.
**Each burst preceded by cold burst standard cartridges to wet chamber.

Abbreviations: L = Low Rate; H - High Rate; M = Mader Lacquer; D - DeBeers Teflon®

inch for standard tests was observed and up to 0.014 inch in special wet tests. In the preferred design "A", Mader coated, no stretch marks were observed in standard tests, and for wet tests, the depth of 0.002 inch was no more serious than for standard aluminum cases later tested under the same conditions.

The conclusion was that the Mader coated design "A" (0.51 lb) is the preferred design. The weight is lower than for designs "B" and "C", and the performance is better.

Shown in Table 15 is quality assurance data applicable to the 354 cases of three different designs shipped to Eglin Air Force Base. Results of this inspection indicate critical dimensions are to tolerances specified, and deviations are minor. Data on weight and volume for samples from each design are included.

Shown in Table 16 are hardness profile data. Three columns are provided to show hardness levels for each of the three designs--"A", "B", and "C"--at five different distances from the base. All hardnesses are within the specified range.

Shown in Figure 21 is a photograph of the grain flow pattern of a sectioned case of one of the earlier thin-wall designs. This figure clearly identifies the fabrication method as rod-extrude-draw with the grain flow lines smoothly following the case contour as it blends from the head to the side wall.

TABLE 15. QUALITY ASSURANCE DATA

30MM Thin Wall Steel Cases, Designs A, B, C - 118 Each - 10 October 1978

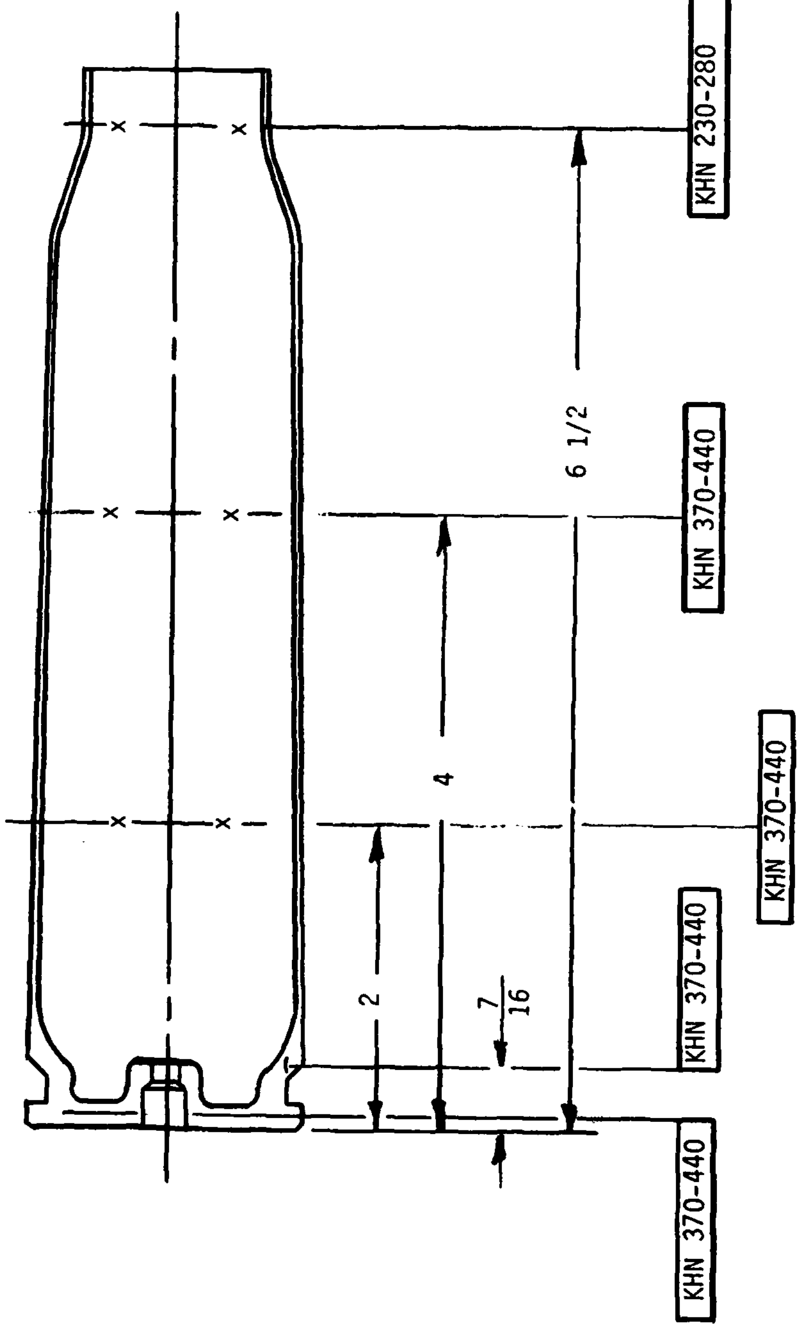
CHARACTERISTIC	ALLOWED RANGE (Units of Measure)	A	B	C
Flange Diameter	1.724 to 1.732	2 o/s 0.001 to 0.002	In Tolerance	1 o/s 0.001
Groove Diameter	1.496 to 1.488	12 o/s to 0.004	2 o/s, 1 u/s to 0.002	In Tolerance
Flange Thickness	1.483 to 1.496	20 o/s, 7 u/s to 0.004	13 o/s, 2 u/s to 0.003	2 o/s, 1 u/s to 0.001
Overall Length	6.796 to 6.811	9 u/s, 2 o/s to 0.004	2 u/s, 1 o/s to 0.003	2 u/s to 0.002
Datum Length	5.970 to 5.982	3 u/s, 2 o/s to 0.003	In Tolerance	In Tolerance
Primer Diameter	0.326 to 0.330	In Tolerance	In Tolerance	In Tolerance
Primer Depth	0.266 to 0.276	8 u/s to 0.003	2 u/s, 1 o/s to 0.006	4 u/s, 2 o/s to 0.003
Mouth ID	1.172 to 1.176	Note 3	In Tolerance	In Tolerance
Mouth Wall Thick.	0.021 to 0.025(A,B)	72 o/s to 0.004	90 o/s to 0.003	
	0.023 to 0.027(C)			30 o/s to 0.001
Flash Hole Dia.	0.253 to 0.258	Note 4	Note 4	Note 4
Chamber Gage		Note 5	Note 5	Note 5
Visual		Note 6	Note 6	Note 6
Eddy Current		In Tolerance	In Tolerance	In Tolerance
Weight (sample of 12 each design)		0.507 lb	0.540 lb	0.566 lb
Volume (sample of 3 each design)		193.0 cc (11.78 cu. in.)	191.8 cc (11.70 cu. in.)	190.0 cc (11.60 cu. in.)

NOTES:

1. All dimensions in inches, unless otherwise indicated.
2. Abbreviations: o/s = oversize u/s - undersize
3. Go gage entered mouth, but with force (slightly undersize)
4. No go gage entered flash hole, but with force (slightly oversize)
5. Cases entered chamber gage with force last one-half inch.
   All loaded cartridges chambered in Eglin Mann barrel easily, a few required initial forcing to improve projectile alignment before chambering easily.
6. Parts were screened initially, with about 20 extra parts consigned to local testing which had medium body flutes or light folds at shoulder.

TABLE 16. HARDNESS PROFILES

DESIGN A	DESIGN B	DESIGN C	SPECIFIED HARDNESS RANGE
266	252	264	KHN 230-280
410	397	412	KHN 370-440
410	392	397	KHN 370-440
406	378	394	KHN 370-440
421	389	400	KHN 370-440



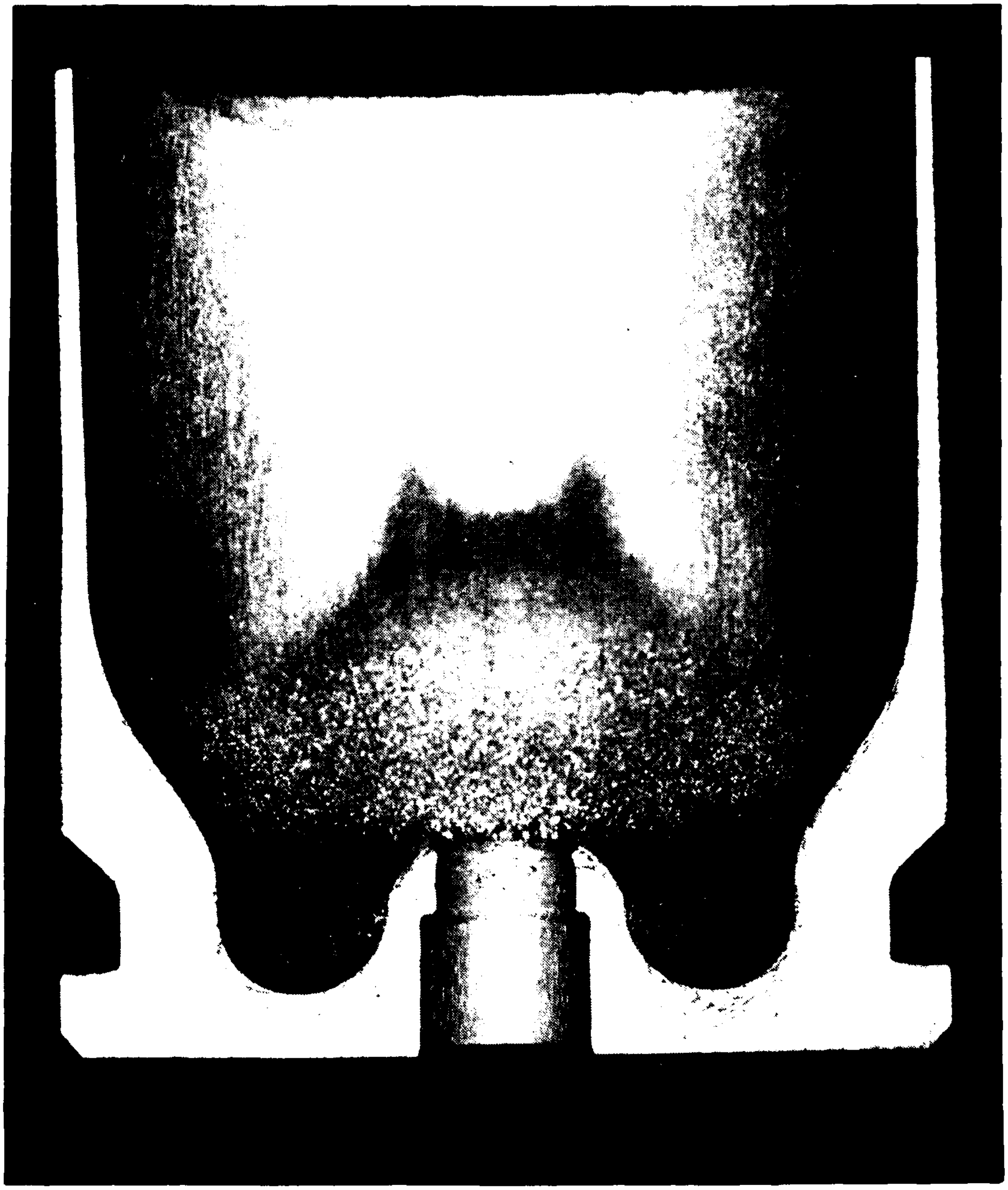


Figure 21. Grain Flow Pattern

SECTION V

FUNCTIONAL CHARACTERISTICS

1. INTRODUCTION

The functional characteristics of the 30 mm GAU-8 thin-wall steel cartridge case have been reviewed in relation to existing GAU-8 specifications for the target practice cartridge, the aluminum case, and the 20 mm M103A1 steel cartridge case. In general, essential functional characteristics are interpreted as those normally found in the cartridge specification, such as debulleting and action time tests. The tests required to demonstrate achievement of those characteristics are identified and described in detail in those specifications. For purposes of this report, references are listed, and the discussion covers elements of those references as applied to the thin-wall steel case. A specification for the thin-wall steel case, PS-5000-GAU-8TW, dated 10 November 1978, was prepared. The latest revision incorporates the changes needed to apply to the preferred design, style "A", Mader finish, covered by Drawing 00012-004.

2. DISCUSSION

Excess Pressure

Excess pressure (paragraph 3.2.1.1 of Reference 1) identifies the test over-pressure condition to range from 71,000 to 76,000 psi, while paragraph 3.2.1.3 of Reference 2 identifies the mean peak pressure plus three standard deviations over the temperature range so as not to exceed 66,600 psi. Since the 66,600 psi appears to be the highest pressure expected, this will be used for the thin-wall steel case in order to avoid overdesign and the addition of unnecessary weight to the cartridge case. Much of the development testing has been at pressure levels of 71,000 psi, but the 66,600-psi level appears best for the specifications.

Muzzle Velocity

Muzzle velocity levels identified in paragraph 3.2.1.3 of Reference 1 will be increased by the order of 150 fps to 200 fps to recognize the increased volume available in the thin-wall steel case.

Debulleting

With the increase in mouth wall thickness to 0.027 inch, per the preferred type "A" 0.51-lb design, where it is now within 0.005 inch of the

aluminum case mouth wall thickness, the bullet pull required is now completely met, even with single groove projectiles.

Case Material

Paragraph 3.7.1 of Reference 1 requires that the case be fabricated from 7000-series aluminum alloy. For the thin-wall steel case, this material will change to 10B22 boron steel.

Protective Coatings

The present 30 mm thin-wall steel case employs an exterior sprayed lacquer over a case which is phosphated inside and out. The phosphating is in accordance with Specification TT-C-490. The thin-wall steel case specification will include data identifying the lacquer selected and tests required to ensure that case structural integrity is satisfactory, and that the exposure to 600 degrees F for 10 minutes does not adversely affect the coating. Tests may be prescribed for the coated case including lacquer hardness, cure condition, and coefficient of friction.

Coupon Tests

With aluminum cases, it is common practice to prepare metal coupons cut from the aluminum case for tensile tests and notch tests. Such coupon tests are not required in steel cases covered by specifications such as MIL-C-50797. The coupon tests are desirable for aluminum cases considering the additional hazards if defects occur in aluminum cases. Although the steel walls are thinner, the potential hazard, based on observation of tests to date, does not appear to justify the expense of performing the coupon tests.

Hardness

The hardness test methods and procedures will be similar to those identified in paragraph 4.4.1 of MIL-C-50797 except for the substitution of the drawing. The thin-wall steel case uses slightly higher hardness levels and changes from Rockwell C to Knoop to permit lower test loads needed for valid readings with the thinner walls. Use of the Knoop also permits more accurate readings.

Classification of Defects

The classification of defects will be about the same as listed in MIL-C-50797.

Full-Scale Development

Qualification tests will be planned to evaluate performance on the thin-wall steel GAU-8 case when made a part of complete cartridges of both the TP and API types. Besides functional and interface tests in the automatic gun, environmental tests in connection with service life tests will be conducted. Accuracy tests in Mann barrel and debulleting tests will also be specified.

REFERENCES

1. Honeywell Specification No. DS 8558 Part II, 20 Mat 1976, Case, Cartridge, 30mm Aluminum for the GAU-8/A Gun System.

2. Aerojet Specification No. A10146 Part II, 6 August 1976, Cartridge 30mm, PGU-15/B (TP).

3. General Electric Interface Drawing 201F400, 10 October 1974.

4. Military Specification, "Case, Cartridge, 20mm M103A1"; MIL-C-50797 dated 25 May 1973, with Amendment No. 1, dated 20 May 1975.

5. Amron Specification No. PS-5000-GAU-8TW, 10 November 1978, Case, Cartridge, 30mm Thin Wall Steel, for the GAU-8/A Gun System.

SECTION VI

RESULTS, CONCLUSIONS, AND RECOMMENDATION

1. RESULTS

Automatic gun tests of the final three case designs resulted in no case casualties. In standard tests at various temperatures and gun rates, there were no internal stretch marks in the "A" case designs, Mader coated, at either normal or excess pressure. In wet tests at excess pressure, minor stretch marks in the Mader coated "A" design cases were noted, comparable to those noted in control aluminum cases. More significant stretch marks were noted in "B" and "C" designs, and in DeBeers coated "A" designs. The stretch marks were circumferential, about one inch from the base of the case.

Mader coated cases of the final three designs gave bullet pull values well above specification requirements.

Muzzle velocities were increased over velocities with the aluminum case by approximately 150 feet per second due to the increased propellant volume in the preferred "A" case design.

A production cost analysis for FY 81 for a typical plant, fully automated, at 250,000 cases per month production rate, showed a cost savings for the steel case over the aluminum case of $0.42 to $0.44 per case.

2. CONCLUSIONS

Structural integrity of the steel case has been demonstrated in automatic gun tests.

Propellant volume of the preferred steel case design is increased by 14 percent, increasing the muzzle velocity by 150 feet per second, resulting in an increase in system performance against tank targets.

An expanded production base to provide a steel case as back-up to the present aluminum case is justified by production studies.

The weight penalty of the thin-wall steel case is 0.19 pound per case, resulting in approximately 200 pounds increase in the ammunition load for the A10 aircraft.

Feasibility of the thin-wall steel case has been demonstrated in test results and production analyses.

3. RECOMMENDATION

It is the recommendation that the 30 mm GAU-8 thin-wall steel case proceed into full scale development and qualification testing.

APPENDIX A

HYDRAULIC BULGE DUCTILITY OF THIN-WALL 30 mm STEEL CARTRIDGE CASES

BACKGROUND

During the development of a new design for thin-wall 30 mm steel cartridge cases, circumferential cracking problems were encountered in some of the proof firings (References 1, 2, and 3) in automatic gun tests. The cracks usually occurred at the transition from the straight to the tapered section. The specified material is grade 10B22 to 15B22 or equivalent steel treated to a hardness of Knoop Hardness Number (KHN) 370-440 equivalent to a tensile strength in the range of 150 to 180 ksi. Data were supplied to show that the flow stress of the material is rate sensitive and can be approximately characterized by

$$= k\, \dot{\varepsilon}^{\, n}$$

where $n = 1.58 \cdot 10^{-2} \pm 1.12 \cdot 10^{-2}$. With increasing strain rate, the instability strain (strain at maximum load) increases from 0.060 at $\dot{\varepsilon} = 4.410^{-4}$ sec $^{-1}$ to 0.076 at $\dot{\varepsilon} = 4.4$ sec^{-1} and 0.088 at $\dot{\varepsilon} =$ 400 sec^{-1}. For the two lower strain rates the failure strain (extension, probably not corrected for necking) is reported to be approximately 0.22. The true fracture strain of the material is estimated to be 1.0 ± 0.3. Thus, the cartridge material would be subjected to an average strain rate of 250 sec^{-1} if failure were to occur at the estimated uniaxial tensile strain. Since the stress state at the location where occasional cracking was observed is multiaxial, the applicability of the above estimates is in question. It was therefore decided to determine the multiaxial fracture ductility at strain rates comparable to those experienced in the actual firing. Date of this type can then be used in the assessment of the cartridge case design-material combination with the help of the multiaxial failure criterion proposed by Weiss (References 4, 5, and 6).

DETERMINATION OF THE DYNAMIC BULGE DUCTILITY

To determine the fracture ductility under multiaxial stress states various bulge, bend, and plate strain tension test procedures have been developed at Syracuse University (Reference 4). Recently a test system design for high strain rate studies by J. Biegel (Reference 7) has been modified to allow the determination of the dynamic ductility under multiaxial stress states. Depending on the test specimen geometry and ductility, the system is capable of strain rates of the order of 10^3 sec^{-1}.

For isotropic materials, the die (female) section of the bulge test device can be circular in cross-section with an appropriate draw radius to insure that fracture occurs near the center of the test zone. When materials are anisotropic, in particular with sheet materials where the biaxiality usually occurs with respect to rolling directions where the principal directions are perpendicular, an elliptic shaped die can be used to determine the true fracture strain in the direction of interest. The strain biaxiality for the elliptical die used here is approximately

$$\frac{\varepsilon_1}{\varepsilon_2} = 2.4$$

where ε_1 is the strain in the direction of the minor axis. From this, Saint-Venant's theory gives a stress ratio of

$$\frac{\sigma_1}{\sigma_2} = 1.32 = 1 + \mu = 1 + 0.32 \quad \text{If} \quad \sigma_2 = \sigma_{yp}$$

A sketch of the test device is presented as Figure A-1.

In the test device used a high pressure is very rapidly generated in the hydraulic fluid (heavy oil) and the specimen is strained to fracture. The fracture deformation is measured with an indicator gage (pointed anvils). The thickness of the thinnest section of the fracture zone is used to determine the fracture strain. The true facture strain is then calculated as the natural logarithm of the ratio of the original to final thickness.

An elliptical die and the first specimen were oriented so that the long axis of the die was perpendicular to the thickness transition zone. The long axis of the fracture section is colinear with the long axis of the die. The second specimen was tested with the thickness transition zone of the specimen colinear with the long axis of the ellipse. Again the fracture section has its long axis colinear with the long axis of the ellipse. The fracture strain of both specimens was calculated as 0.32*. The strain rates approximated 3×10^3 sec^{-1}.

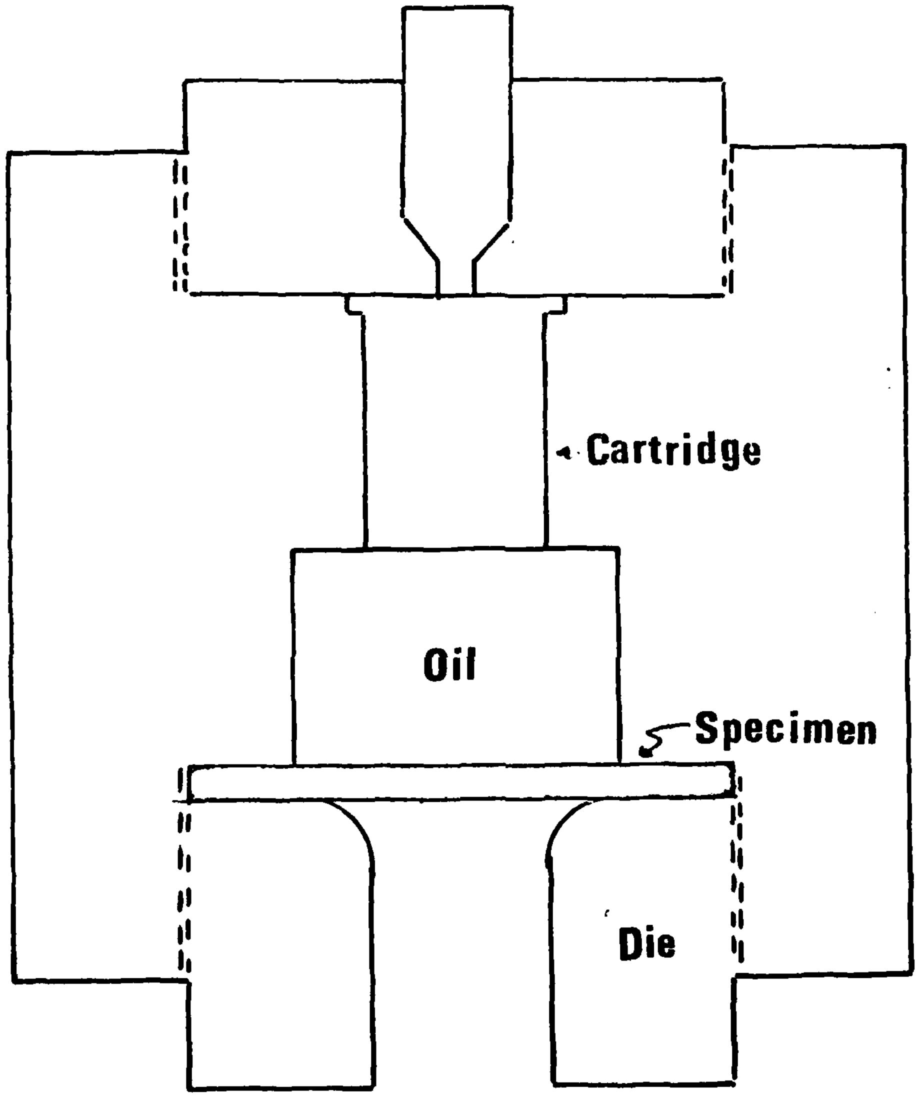


Figure A-1. Cross-Section of Test Device

DICUSSION

This fracture strain refers to a stress state of

$$\sigma_1/\sigma_2 \simeq 1.32$$

or a strain state of

$$\varepsilon_1/\varepsilon_2 = 2.4 .$$

Of interest to the case performance is the fracture strain for the actual stress state which exists during firing. Unfortunately this value is not known. One may estimate it from the assumption that the circumferential strain, ε_3 , is negligible compared to the longitudinal strain ε_1 , and the thickness strain, ε_2 . From this assumption, it follows that

$$\varepsilon_1 = -\varepsilon_2$$

or

$$2\sigma_3 = \sigma_1 + \sigma_2$$

with σ_2 being the chamber pressure ($\rho = -\sigma_2$) .

* $\ln t_0/t_f = \ln 0.019/0.0138 = 32.$

For the cartridge material and from the finite element results, one may estimate a stress state at failure of

$$\sigma \approx 160 \text{ ksi} \quad \sigma_2 \approx -70 \text{ ksi and } \sigma_3 \approx 45 \text{ ksi}$$

i.e., stress ratioes of

$$\alpha = \frac{\sigma_2}{\sigma_1} \approx -0.44 \text{ and } \beta = \frac{\sigma_3}{\sigma_1} = 0.28.$$

Under these conditions one can estimate (Reference 5) a fracture strain in service of about 2.8 x 0.32 or 0.91*, i.e., the 0.019-inch-thick case would thin to 0.0076* inch at the fracture point.

It should be noted that these are rough estimates only. To obtain more accurate correlation, additional testing and additional information on the stress state during firing would be required. Qualitatively, it can be stated that an increase in σ_3, the circumferential stress, due to an expansion of the barrel during firing ($\varepsilon^3 = 0$ no longer justifiable) would reduce the fracture strain. For example, if $\sigma_3 \approx 70$ ksi, one would obtain an estimated fracture strain of 0.78, i.e., approximately 14 percent less than for the stiff barrel case. Friction effects could further influence the results.

* $\varepsilon^{0.91} = 2.48; \quad \frac{0.019}{2.48} = 0.0076$

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1. Rayle, Roy, "Status Report No. 5, New Cartridge Case Concepts Thin Wall 30mm Steel", July 1977, Amron Corporation, Contract No. F08635-77-C-0092.

2. Rayle, Roy, "Status Report No. 7 New Cartridge Case Concepts Thin Wall 30MM Steel", September 1977, Amron Corporation, Contract No. F08635-77-C-0092.

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5. Weiss, V. Kasai, Y. and Sieradzki, K., "Microstructural Aspects of Fracture Toughness", Special Technical Publications 605, 1976, American Society for Testing and Materials.

6. Weiss, V., "Recent Advances in Notch Analysis of Fracture and Fatigue", Ingenieur-Archiv, 45 (1976) p. 281-289.

7. Biegel, J., Tensile Test Device, U.S. patent No. 3,517,551, June 30, 1970.

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AFIS/INT	1
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